Plasterboard technical report

Capture of waste plasterboard on construction sites

Demonstrating cost-effective solutions to the capture of waste plasterboard on construction sites

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Front cover photograph: Plasterboard capture system at Block H, Clarence Dock, Leeds

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Context

WRAP

WRAP (Waste & Resources Action Programme) works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment.

Established as a not-for-profit company in 2000, WRAP is backed by Government funding from Defra and the devolved administrations in Scotland, Wales and Northern Ireland.

WRAP and plasterboard

Through its Construction Programme, WRAP is helping the construction industry cut costs and increase efficiency through the better use of materials.

Plasterboard is used extensively in the construction and refurbishment of buildings as a lining for walls and ceilings, and for forming structures such as partitions.

Plasterboard waste can arise on construction sites for a number of reasons, including wasteful design, offcuts from its installation, damaged boards, and over-ordering. It is estimated that over 300,000 tonnes per year of waste plasterboard is produced on construction sites. It can also arise from strip-out activities during refurbishment and demolition projects; the waste arisings from this source are significantly higher. In total it is estimated that over one million tonnes of waste plasterboard are produced each year from construction and demolition activities.

Most of this waste is currently disposed to landfill, even though it can be easily recycled. WRAP receives funding from Defra through the Business Resource Efficiency and Waste (BREW) programme to divert plasterboard waste from landfill by working to overcome the barriers to plasterboard recycling. Additional funding is also received from the devolved administrations in Scotland, Wales and Northern Ireland.

WRAP is working to overcome these barriers through the following key areas:

- plasterboard waste minimisation;
- site waste management;
- segregation and collection of plasterboard waste;
- development of infrastructure, including waste logistics and recycling capacity;
- market development for materials from plasterboard recycling – recycled gypsum and reclaimed paper;
- education, awareness and behavioural change; and
- informing and influencing legislation, regulations and policy.

More information on WRAP's work can be found at www.wrap.org.uk/construction

Executive summary

Over one million tonnes of waste plasterboard are estimated to be produced each year in the UK from construction and demolition activities. Most of this waste is currently sent to landfill, even though it can easily be recycled. WRAP is working to divert plasterboard waste from landfill by seeking to overcome the barriers to plasterboard recycling. One area of its work is to develop markets for the materials from plasterboard recycling (recycled gypsum and reclaimed paper). This project describes work undertaken on a number of construction sites to demonstrate cost-effective solutions to problem of how best to capture waste plasterboard for recycling.

The project was undertaken by a consortium including Taylor Woodrow, Starke Arvid and British Gypsum.

Trial design

The aims of the project were to:

- develop the general understanding of site characteristics important when planning plasterboard capture and other waste minimisation methodologies on construction sites;
- provide information to support the uptake of the most efficient means of plasterboard capture identified by this study; and
- stimulate further investigation of capture methodologies for those sites shown not to be suited to traditional capture methodologies.

The project did not examine steps to reduce the generation of plasterboard waste (i.e. waste minimisation), the infrastructure for plasterboard waste recovery/recycling and different waste management options for plasterboard.

A previous project (PBD006011) examined the plasterboard capture systems at four Taylor Woodrow Construction (TWC) sites covering both high rise and low rise residential developments. This project focused on trials at high rise developments because such sites appeared to offer the largest cost savings (reflecting the traditionally high cost of moving plasterboard waste out of high rise buildings). These trials were located as follows:

- Block H Clarence Dock, Leeds – Taylor Woodrow;
- Blocks C2 and D Clarence Dock, Leeds – Shepherd Construction; and
- King's Place, King's Cross, London – Sir Robert McAlpine.

The King's Place trial offered the opportunity to trial a bespoke plasterboard capture system from the beginning of the construction project. It also allowed the environmental impact of road and barge transport of the waste plasterboard to be compared.

The plasterboard capture system utilised in all three trials incorporated a Starke Arvid chipper in order to improve efficiency by increasing the capacity of the skip or bag used for collection. One of the sites featured in the previous project (PBD006011) at The Square at Grand Central, Aylesbury, used a chipper supplied by Optimum Recycling Solutions. The results from this trial were therefore included in the analysis undertaken to present the economic and environmental business cases for a best practice plasterboard capture system including the use of chipper.

Use of the chipper

The development and trial of the chipping machine manufactured specifically by Starke Arvid to reduce the bulk of waste plasterboard formed a substantial part of the project. The importance of effective operator training was one of the main lessons learnt. The Starke Arvid chipper is now in full-scale production for worldwide sales.

Economic business case

The economic business case proved the primary driver during the trials and an important means of buy-in from site management to the plasterboard capture system.

Existing capture systems on UK construction sites have significant potential for improvement. Significant cost savings through a reduction in labour costs and waste disposal costs (per m^3) can be achieved by implementing

an effective plasterboard capture system designed to take account of site conditions. Cost savings are possible at all three stages of waste plasterboard capture:

- collection of waste into bins;
- movement of waste from the source floor to the ground floor or access point to a chute; and
- movement of waste to final receptacle for off site removal.

Results from the trials undertaken in this project identified that measures to reduce manual handling and increase the quantity of material in the skips/bags could achieve savings of up to 47% on the total costs of waste plasterboard capture.

Environmental business case

The environmental business case focused on the use of a chipper to maximise the amount of waste material within a receptacle (e.g. bag, skip or barge) and consequently optimisation of its transportation off site for recycling.

An analysis of historic data from a range of Taylor Woodrow sites suggested that four variables can affect the level of carbon dioxide emissions associated with the transport of plasterboard waste from the site for recycling/disposal. These variables are:

- increase in skip/bag capacity through use of a plasterboard chipper;
- use of different size receptacles for waste plasterboard;
- distance of the site from a plasterboard recycling centre; and
- mode of transport used to transport the plasterboard.

An ideal scenario would address all four through the use of a chipper, use of a 40 cu. yd skip (or larger), a shorter journey distance and an alternative means of transport (such as a canal barge).

Best practice guidance

The many lessons learned from the site trials have been brought together in the form of best practice guidance. This guidance is intended to inform the implementation of plasterboard capture system on future sites and to provide a framework around which to target continual improvement. The guidance stresses the importance of planning and highlights the roles/responsibilities of the key stakeholders (main contractor, dry lining contractor and waste management company/plasterboard recycler) at each stage in the process.

Conclusions

The project demonstrated a clear business case for the effective planning and implementation of plasterboard capture systems (including the use of chippers if appropriate) on high rise construction sites. The use of a plasterboard chipper improved efficiency in terms of both labour costs and waste disposal costs at all sites trialled apart from one. The trials highlighted the chipper's potential and the need for well-planned capture systems that take account of critical factors at the site (space, time, client requirements, location, duration, size of waste stream, waste disposal regulations).

The distance to the recycling centre, the size of waste container, use of a plasterboard chipper and mode of transport can all have an impact on reducing the carbon dioxide emissions associated with the transport of waste plasterboard off site for recycling.

Both existing and new construction sites are urged to examine how an effective plasterboard capture system could be implemented and to follow the best practice guidance suggested in the report.

Recommendations

The site trials highlighted the considerable work still needed to minimise the generation of plasterboard waste on site and to improve waste management practices within the dry lining sector.

There is also a need to develop cost-effective solutions to the capture of waste plasterboard on low rise developments.

Contents

1.0 Introduction

This final report for project PBD007011 describes work undertaken on a number of UK construction sites to demonstrate cost-effective solutions to the problem of how best to capture waste plasterboard on construction sites for recycling. The plasterboard capture systems used during these trials all incorporated a chipping machine designed specifically to reduce the bulk of waste plasterboard in the collection receptacle.

The project aimed to:

- develop the general understanding of site characteristics important when planning waste plasterboard capture and other waste management measures on construction sites;
- provide information to support the uptake of the most efficient means of waste plasterboard capture identified by the study; and
- stimulate further investigation of capture systems for those sites shown not to be suited to traditional capture methodologies.

The project did not cover:

- steps to reduce the generation of plasterboard waste (i.e. waste minimisation);
- the infrastructure for plasterboard waste recovery/recycling; and
- comparisons between disposal routes (although some are made to illustrate cost perceptions about plasterboard recovery).

This project (PBD007001) built on work undertaken under an earlier WRAP project (PBD006011).

1.1 Report structure

Section 1 outlines the roles played by the different project partners, the work undertaken during the various phases of the project and the controlled trial at Wastecycle Ltd (www.wastecycle.co.uk). The next two sections describe the sites that took part in trials during a previous project (PBD006011) and the sites participating in this project (PBD007011) respectively, together with the lessons learnt from both sets of trials. Section 4 contains details about the chipper supplied by Starke Arvid and its development during the project.

In order to persuade site managers of the advantages of operating an efficient capture system for waste plasterboard, two business cases were developed reflecting the findings of this study. The economic business case is examined in section 5 and the environmental business case in section 6.

Section 7 brings together the lessons learnt from the site trials as guidance that details the steps necessary for planning, implementing and maintaining a best practice plasterboard capture system on construction sites. The final section draws conclusions from the project and sets out recommendations for future work.

1.2 Project roles

The roles taken by various project partners are summarised in Table 1.

Table 1 Project roles

Company	Role	Notes
Taylor Woodrow (www.taylorwimpey.com)	Lead partner Project management Data capture – field trials Analysis Conclusions and dissemination	Taylor Woodrow Construction (TWC) is a leading developer of high quality homes in sustainable communities across the UK. In addition to building new homes, the company is also a major contractor with over 90 construction sites ongoing at any one time covering every aspect of plasterboard use. TWC operates a dedicated in-house environmental consultancy and waste management team providing consultancy and expertise to the construction and developments divisions as well as external clients. TWC is part of Taylor Wimpey plc.
Starke Arvid (www.starkearvid.se)	Partner Manufacture of chipper Data capture – field trials Analysis Conclusions and dissemination	Starke Arvid produces intelligent material management equipment, developed to make work easier within the construction, transport and manufacturing industries. Starke Arvid has developed a dedicated capture technology in the form of a plasterboard chipper under trial as part of the project.
British Gypsum (www.british-gypsum.bpb.co.uk)	Partner Provision of technical support to the project	British Gypsum is the UK's leading supplier and foremost authority on internal wall and ceiling systems, with a long history and a proven record of providing effective lining solutions for many of the world's most prestigious buildings. British Gypsum provided technical support, data and guidance to the project as providers through its Plasterboard Recycling Service (PRS) of TWC's plasterboard recycling system.

1.3 Project phases

The work undertaken during the various phases of the project is summarised below. Apart from Milestone 2, reports were prepared for WRAP at the end of each milestone.

1.3.1 Pre-project trial

A one-day trial using a prototype of the Starke Arvid chipper was carried out on 30 August 2006 at a TWC site. This trial was undertaken to evaluate the following in a live site environment:

- a noise test to confirm that the chipper did not exceed the 85 dB(A) limit for use of plant on site without the use of personal protective equipment (PPE);
- an evaluation of the equipment against the operational parameters set out by WRAP during the earlier project (PBD006011);
- a speculative analysis of the labour requirements for the equipment based on its current configuration; and
- potential considerations for the chipper's ongoing development.

1.3.2 Milestone 1

During this first phase of the project, all existing (technical and market) knowledge and expertise within the research consortium relevant to the planning stages of the site trials was collated within a desk study. This covered:

- construction site characteristics and their impact on site waste minimisation/management methods;
- different plasterboard capture systems already in operation on TWC sites;
- causes of waste during the dry lining process;
- constraints on the recycling of plasterboard waste; and
- the plasterboard chipper and some potential partner methodologies for use during the project.

1.3.3 Milestone 2

The second phase of the project consisted of the manufacture of a number of plasterboard chippers based on the recommendations made during the pre-project trial. This included:

- a visit to a tool factory belonging to Alia (parent company of Starke Arvid) at Ljungskile, Sweden; and
- visits to two constructions sites where these tools are being used as part of plasterboard capture systems.

The lessons learned from this visit were recorded in a visit report and incorporated into later project milestones. The chippers were manufactured at the Alia factory and shipped over to the UK during the second week of November 2006.

1.3.4 Milestone 3

During milestone 3, the construction sites for the trial were selected and the methodology for data collection finalised. A period of data collection on the existing systems was then undertaken to act as a control for the project.

The data collection was tailored to address the economic and environmental business cases for the chipper. This included monitoring:

- time spend on materials handling;
- the cost of this time (labourers) in £/hour;
- skip weights; and
- skip costs (waste management contractor) in £/tonne.

Once the new capture system was in operation, data collection was extended to include the cost of hiring the equipment – chipper, bins and chute.

The rationale for the site selection reflected three aims of the research project, i.e. to carry out trials on sites:

- producing significant quantities of plasterboard waste such that, while they might pose the greatest challenges to implementing a new system, they would also offer the greatest potential reward in terms of demonstrable savings;
- suspected of currently sending plasterboard waste to landfill; and
- where the chipper stood the best chance of achieving savings, e.g. the environment offered by a high-rise residential project (suitable power supply on site, quantity of material, significant existing labour costs) is likely to be more suited to the chipper than the environment offered by a traditional housing site (where there is limited power until the final few weeks of the project, a diffuse source of plasterboard waste and likely to be less plasterboard waste per unit).

Although the original intention was to use TWC sites exclusively for the purpose of these trials, it quickly became apparent that this would not be possible because:

- the timing of the trials did not fit well with current TWC sites as the majority of the dry lining work had already been completed in time for residential handovers prior to Christmas 2006; and
- all TWC sites producing significant quantities of plasterboard waste take advantage of the British Gypsum Plasterboard Recycling Service (PRS) with the result that very little plasterboard waste is sent to landfill.

It was therefore necessary to look at other sites in the industry for suitable trials. This was done with the help of sub-contractors in Taylor Woodrow's supply chain and through Starke Arvid contacts. This approach also had the advantage of giving a broader perspective to the project.

1.3.5 Milestone 4

By 2 March 2007, a significant amount of work had been undertaken to:

- examine the capture systems in operation on sites; and
- improve these systems (and in some cases applying an entirely new methodology) based on the lessons learned during the trial.

To confirm the revised capture systems were proving successful, a further period of data collection was undertaken against the same criteria used in Milestone 3. This included qualitative data capture in terms of how the site stakeholders viewed the revised capture systems such that best practice and lessons learned could be recorded for future applications.

The Milestone 4 report provided an update on the data collection already completed, including the planned revisions to the capture systems proposed for implementation on site. The report also contained some preliminary analysis based on the data collected during the control period, which provided some indication as to where the inefficiencies lay with the control capture systems.

1.3.6 Milestone 5

Milestone 5 consisted of an update on the trials and an explanation of the methodology proposed to produce the economic and environmental business cases.

1.3.7 Milestone 6

Towards the end of March 2007, trial work finished on one of the sites and consequently a new site was found for trial. This new site offered a good opportunity to test a best practice capture system from the outset of a project. This has been a stumbling block in the past as, once implemented, sites were often reluctant to change their capture systems.

The Milestone 6 report contained:

- an update on progress with each of the capture systems under trial;
- some preliminary results for these capture systems in terms of the economic and environmental business cases presented in this final report; and
- some of the technical development made to the chipper throughout the course of the project (extended and recorded in section 4.2 of the final report).

1.4 Controlled trial at Wastecycle Ltd

It became increasingly apparent during the project that there was a need for a trial of the chipper under controlled conditions (i.e. conditions that could be fully monitored). This trial was undertaken at the Wastecycle transfer station in Nottingham (part of the British Gypsum PRS system).

This trial facilitated an accurate assessment of the time taken to fill both a British Gypsum bag and an 8 cu. yd skip. It also allowed an accurate comparison of manual handling and chipping into both these receptacles in respect of the time taken and the weights that could be achieved. These data were used to inform the economic and environmental analyses.

2.0 Lessons learned from earlier site trials

During the course of the earlier project (PBD006011), trials of plasterboard capture systems took place on four TWC sites (Table 2).

Table 2 Sites involved in earlier trials (project PBD006011)

Construction type	Location
High-rise residential	Victoria Wharf, Cardiff St James Apartments, Cheltenham
Low-rise residential	The Square at Grand Central, Aylesbury Higher Broughton, Salford)

The aim of these trials was to:

- examine the capture system at operational sites against a set of criteria (the basis of the economic business case – see section 5); and
- establish a benchmark performance standard for any replacement capture system (specifically one involving a plasterboard chipper).

Subsequently two sites (Cheltenham and Aylesbury) were trialled with the addition of a chipper. This was partly to establish:

- compliance of the machinery with the performance criteria devised by WRAP and the health and safety department at Taylor Woodrow; and
- the most beneficial scenarios for a chipper (the quick wins).

Summaries of these trials are given below.

2.1 Victoria Wharf, Cardiff

Victoria Wharf is a high-rise residential development located in Cardiff Bay. The development consists of three phases over four years (Table 3) and is due for completion in 2008. The project is currently mid-way through Phase 3 of the project.

Table 3 Victoria Wharf information

Phase	No. of flats	No. of blocks	No. of floors	Plasterboard provider
1	154	3	6 / 7 / 8	Lafarge
2	126	2	6 / 10	Lafarge & British Gypsum
3	172	2	10 / 14	British Gypsum

The development consisted of 452 (1–3 bed) apartments spread over seven blocks between six and 14 storeys in height. The blocks under construction at the time of the site visits (and therefore the blocks that form the basis of this comparison) were Blocks 6 and 7. Block 6 consists of 42 apartments and Block 7 consists of 84 apartments. Since Block 6 was a similar design to those constructed under Phase 1 of the project, the decision was taken to use Lafarge board for the build. However, this was the last block to use Lafarge board with the remaining 256 flats using British Gypsum board.

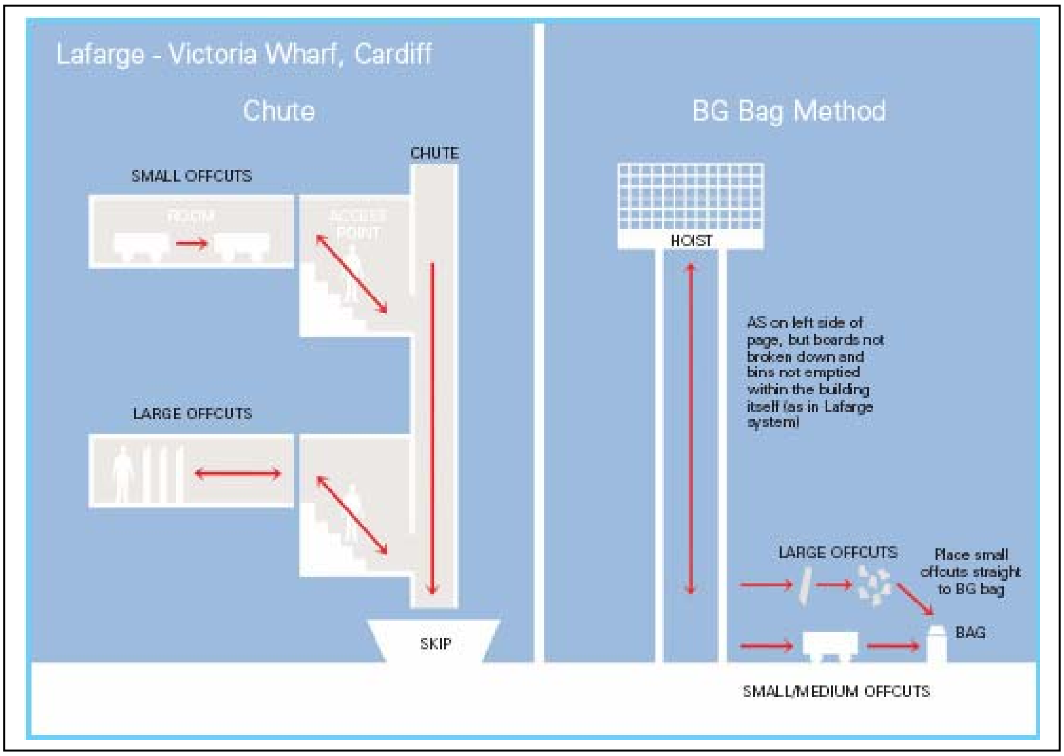
The budgeted quantity for the 126 units under investigation in the case study was 31,786 boards (average 252 boards per unit). It was not possible to confirm the total quantity used on the Blocks 6 and 7 as the dry lining was ongoing and the budgeted board was likely to be an overestimate of the required number of boards.

The site has relatively good storage provisions for both new board and plasterboard waste. It also has the use of a hoist and a plasterboard chute to bring material both up and down from the working floors.

At the time of the trial, the project had two plasterboard capture systems in place. One of these systems operated for buildings using Lafarge boards and the other for buildings using British Gypsum boards.

At the time of the trial, British Gypsum boards could only be returned to the manufacturer if offcuts were loaded into specialised British Gypsum bags. Lafarge board could be loaded into skips. When full, British Gypsum bags did not fit easily around the core of the buildings under construction and therefore final loading into these bags had to take place outside the building at ground level. This had implications on the capture system method (requiring additional activities) compared with Lafarge board. Figure 1 provides a schematic of the capture system at Victoria Wharf. British Gypsum bags are referred to in this figure and others as ‘BG bags’.

Figure 1 Schematic of the plasterboard capture systems used at Victoria Wharf, Cardiff



The main conclusions from this trial were as follows.

- The chute to skip system benefited from a bespoke design and achieved an average 27% saving over the more restrictive hoist and bag method. The smaller number of steps in the chute to skip capture process proved very effective when compared with those of the hoist and bag system. The subsequent move to plasterboard skips by British Gypsum (in addition to bags) is likely to bring the costs of running such as capture system on a high-rise project in line with those incurred with the chute to skip system.
- Larger offcuts were more difficult to dispose of than smaller ones. Whereas the smaller offcuts had an established mode of transport (in the form of wheelie bins), the more intensive manual handling associated with the large offcuts cost more than the disposal of small offcuts.
- Breaking plasterboard offcuts down into pieces small enough for both the chute and, more significantly, the British Gypsum bag was the most significant cost associated with both capture systems for the smaller offcuts. For the larger offcuts, the transport time to the access point proved the most costly.
- The additional health and safety issue associated with manual breaking up of plasterboard offcuts made it the highest priority to address.
- There appeared to be a clear benefit in using the chipper to overcome the manual handling issue associated with the breaking up of offcuts. If the chipper can be located at the point of waste generation, then the associated transport costs to access point could provide a valuable opportunity for savings.
- Further savings may be available from a better compaction rate in the final receptacle.

Potential issues for the development of the chipper raised as a result of this study include:

- the frequent assertion by British Gypsum that it cannot accept offcuts <120 mm in size in its bags (because its recycling plant cannot separate the paper from the plasterboard on pieces below this size); and
- access on site to a power supply of the correct size – as some sites may not have access to a 32 amp supply, the power supply required by the chipper should be 16 amp, 110 volts.

There was widespread support for such a capture system from within TWC and its plasterboard contractors.

2.1.1 Capture system considerations

- The choice of plasterboard may have implications for the type of capture system in place on a site. For instance, most of the Taylor Wimpey sites using British Gypsum board use the bag system. For TWC sites where the choice of board is the responsibility of the client or site, the choice of end receptacle is less prescriptive.
- Phased developments may mean that capture systems suitable on earlier stages are no longer possible on later stages. In this case, it was not possible to replicate the chute system operated for the Lafarge system on later stages using British Gypsum board because there was insufficient space at the building footprint boundary to site a skip.

2.2 St James Apartments, Cheltenham

This new residential development consists of 142 one and two bed apartments being constructed for Crosby Homes. The development is a concrete structure to the fifth floor, with a steel frame on the sixth (top floor) of the building.

A trial of the plasterboard chipper developed by Starke Arvid took place at St James Apartments in Cheltenham on 30 August 2006. This one-day trial was undertaken for the same reasons as given in section 2.1 for Victoria Wharf.

At the time of the trial, the project was a substantial way towards completion (18 months in) with completion scheduled for January 2007. Remaining construction activities consisted predominantly of second fix fit-out, with the first of two handovers occurring in October 2006.

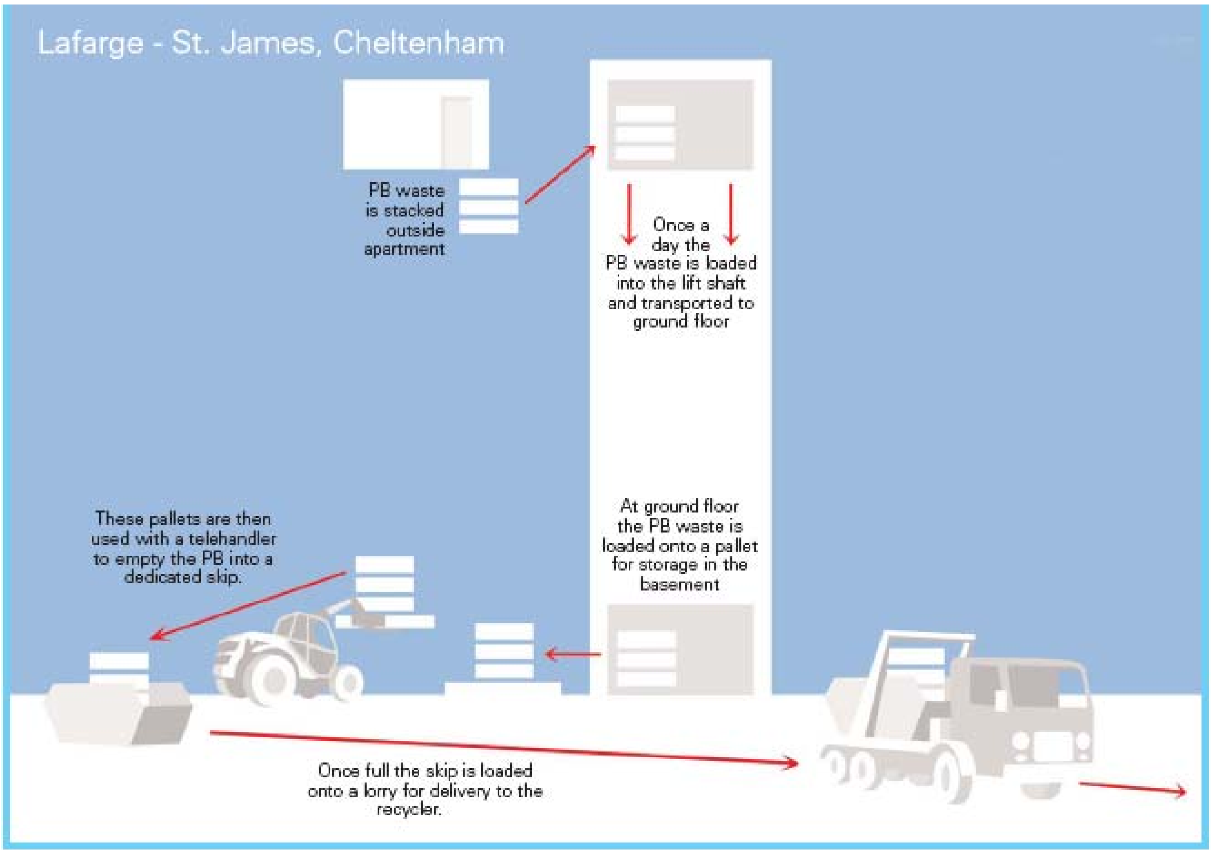
The site used Lafarge board for all apartments, with Wastefile UK (www.wastefile.com) providing the waste management services for the return of the waste plasterboard.

During conversations with the plasterboard subcontractor (TJ Services), it was estimated that an average of 120 boards were to be used per apartment with 2,700 mm wallboards and 2,400 mm ceiling boards being used. It was estimated that the equivalent of approximately 2,000 boards would be wasted during the construction process.

The capture system in place was active at most once a day, with operatives storing waste board outside each apartment until fixing had finished for the day and the clear-up started. Unfortunately, it was not possible to observe this during the site visit as the dry lining process was delayed and insufficient waste board had been produced to warrant a clean-up. The sub-contractor stated that three hours per labourer were allocated for four labourers to complete this process.

Figure 2 provides a schematic of the plasterboard (PB) capture system at St James, Cheltenham.

Figure 2 Schematic of the plasterboard capture system at St James, Cheltenham



2.2.1 Capture system considerations:

- It was not feasible to provide a chute on the external face of the building. However, the design of the building allowed for skips to be placed in the basement car park located in the central atrium. Although this was accessible, the disparate creation of the plasterboard waste prevented the installation of a chute system.
- The severely restricted access on this development influenced the size and types of skips accessible on site. For example, it was not possible to use anything larger than an 8 cu. yd skip due to the restrictions on the size of lorry able to access the basement car park (anything larger would not fit under the soffit of the building).
- The capture system changed as the development progressed with the installation of a central hoist in the lift shaft and a change in location for the skips.

2.3 The Square at Grand Central, Aylesbury

A trial of the plasterboard chipper developed by Optimum Recycling Solutions (ORS) was undertaken at this development between 11 September and 15 September 2006.

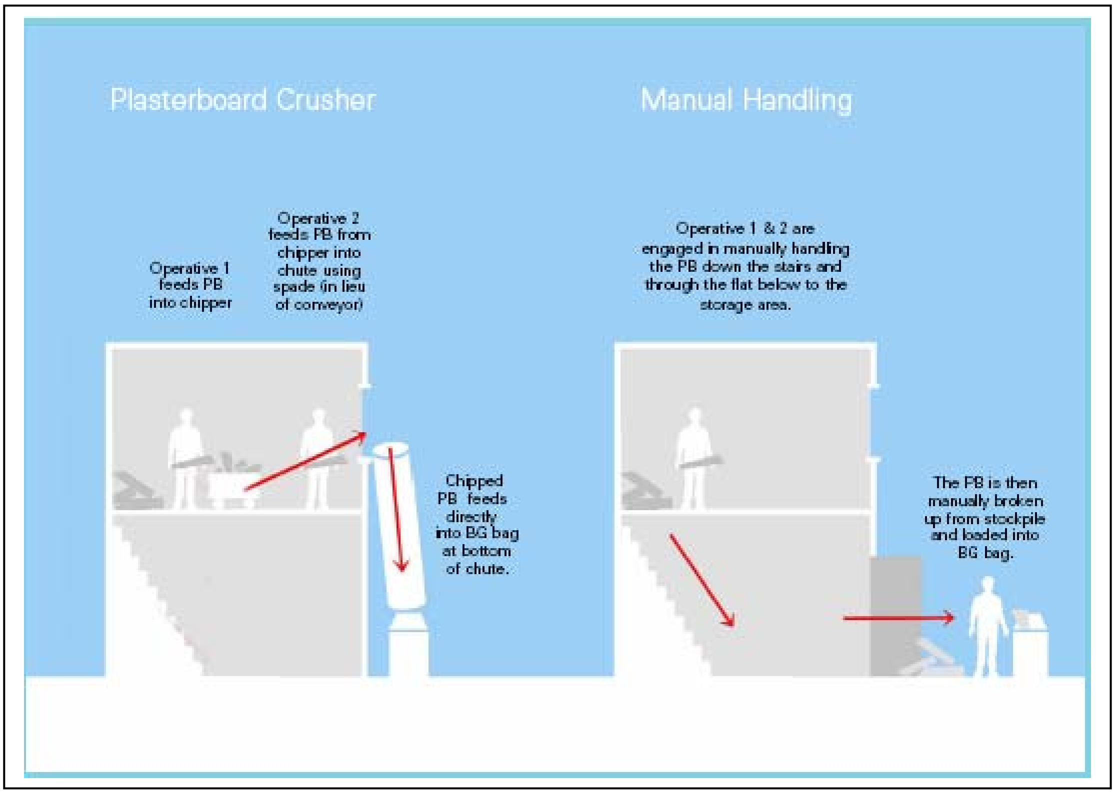
The development at Aylesbury consisted of 144 one-, two- and three-bed apartments over blocks with three and four floors. Completion was scheduled for January 2007 but, at the time of the trial, the project was running slightly behind schedule.

Dry lining activities were carried out by Quality Textures Limited (QTL). At the time of the trial, dry lining activities were not progressing at full capacity due to more weather-proofing being required on the development.

Two capture systems were in operation before the trial of the ORS chipper. One involved the labourers handling the board out of the building manually to a central storage point while the other utilised the tower crane to hoist out full British Gypsum bags.

Figure 3 provides a schematic of the capture system at this development with and without the chipper.

Figure 3 Schematic of the plasterboard capture system at The Square, Aylesbury, with and without the chipper



Use of the chipper resulted in a 51% saving in labour costs. This is likely to have been much higher had the trial taken place on level 3 rather than level 1, but the schedule of works made this impossible to achieve in the time frame available.

The volume reduction in the receptacle represents approximately one extra British Gypsum bag for every seven used on site. When extrapolated across the whole development (assuming 90 plots at a minimum of two bags per plot at £15 per bag), this equates to a cost saving of £386 over the course of the trial.

2.3.1 Capture system considerations:

- Monitoring waste management on this site was a very time-consuming process due to the relatively slow pace of plasterboard installation. In order to trial the chipper, it was necessary to allow a few days of waste to build up before using the machine. A recommended minimum of five fixers is needed to maintain a sufficient quantity of waste to feed through the chipper.
- Data collection needs to be both rigorous and of sufficient volume to enable complete analysis.
- Close liaison with the site management and banksman allowed for a smooth trial. The pace of construction on another site may make this harder to achieve and therefore the earlier these parties are brought into the trial the better.

2.4 Higher Broughton, Salford

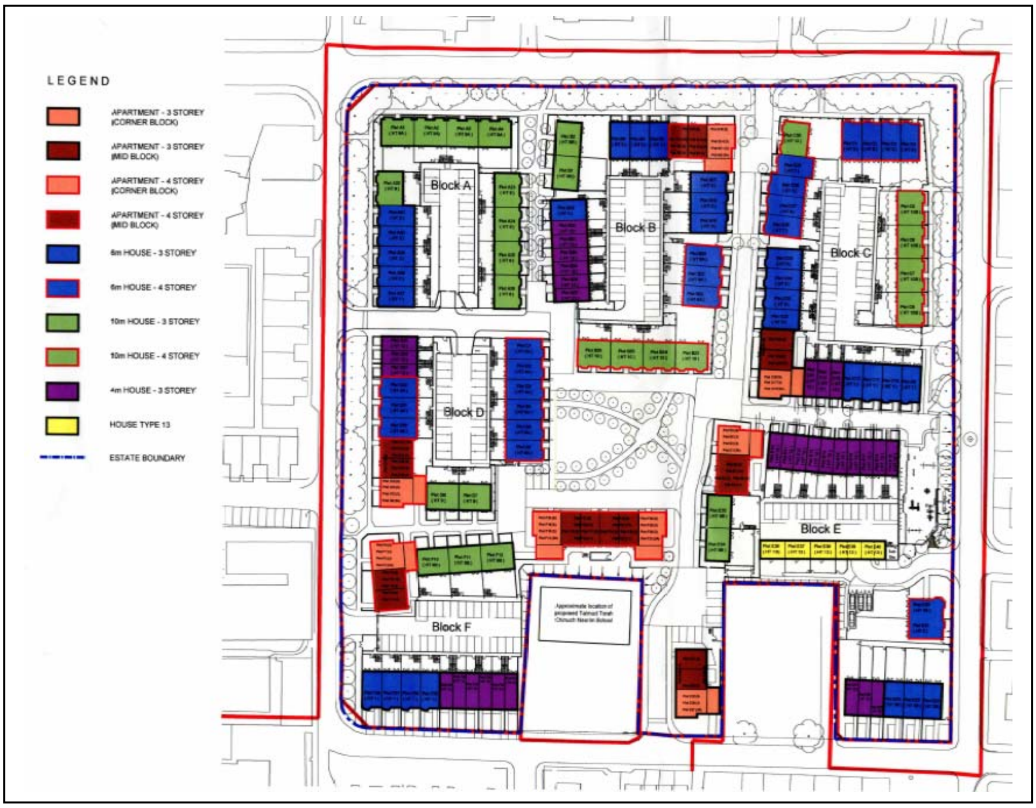
During June 2006, a control trial was undertaken at a residential development in Salford. A chipper trial was not considered feasible due to complications associated with collecting waste on this development – particularly the many sources of waste.

The site is a residential development in Salford that forms a major part of Salford City Council's Regeneration Plan in partnership with public and private companies. The overall development will last seven years and consists of approximately 700 new houses.

The phase under construction at the time of the trial was Phase 1. This occupied a 30-acre site and included a mix of apartments and town houses ranging from two to four storeys (Figure 4). The various blocks of housing within Phase 1 were at different stages of construction, with the plasterboard fit-out taking place in the east of Block B.

The apartments forming the basis of the comparison were four storeys high and were accessed by a shared stairwell. The houses were three storeys high with a dedicated stairwell within each house.

Figure 4 Higher Broughton site plan



Waste generation varied slightly from apartments to houses, since a team of fitters worked only on one block of apartments at any one time, whereas six different houses could be fitted simultaneously. Although moving waste was labour-intensive, the number of sources of waste made it difficult to apply a consistent capture methodology.

The plasterboard capture system used at Higher Broughton is based around the labour resource. The labourers supplied by the dry lining sub-contractor are responsible for supplying the new boards and removing the waste produced by the fixers.

When the plasterboard is cut to size, the offcuts are stored in the rooms for future use. This good practice means that only the smaller pieces are collected for disposal, resulting in a major reduction in the amount of waste being sent for disposal.

Currently there is no dedicated system for removing the waste. Once a sufficient quantity of waste has been collected, the labourers carry the waste manually down to British Gypsum bags situated outside the apartments and houses. Due to the pressure on the labourers to supply new boards, the waste disposal operation tends to occur at the end of the working day when the fixers have finished. This activity can last up to an hour.

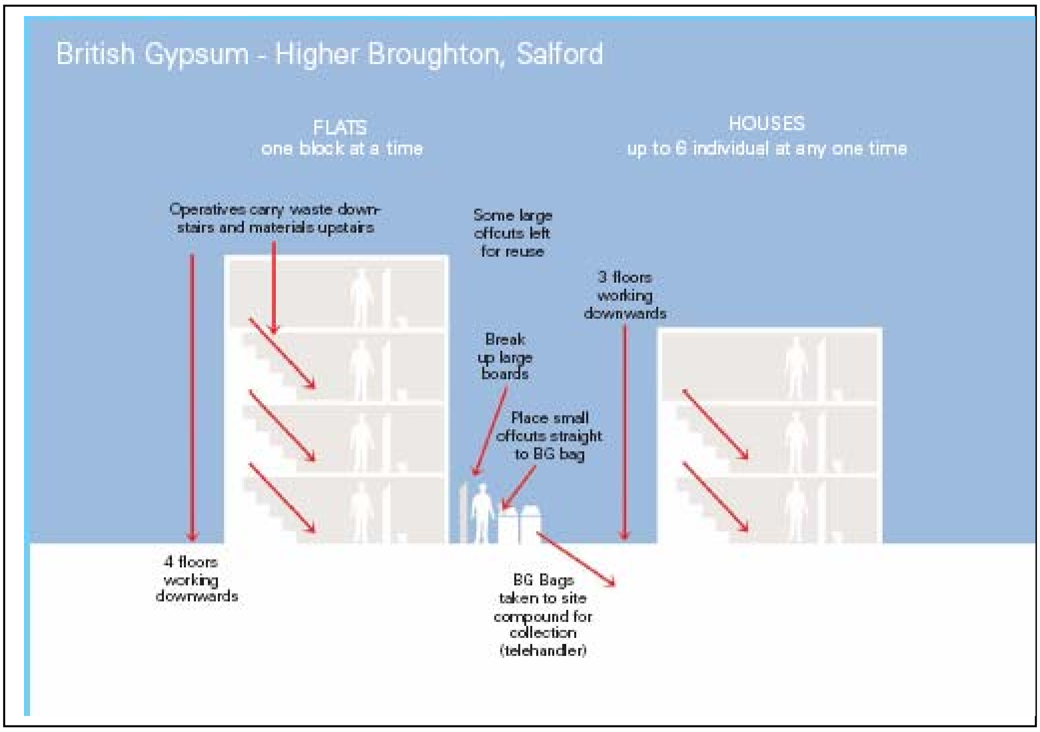
Once the waste is carried down the stairs, the larger offcuts are used to shape the bag and the rest are placed into the bags, being broken down if necessary. The labourers repeat this process until all the collected waste is removed from the buildings.

Once the bags have been filled, a forklift moves the bags to a compound where they are stored until a sufficient number is available for collection by British Gypsum (usually a minimum of 6–10).

The site has good storage for both new plasterboard and waste waiting to be collected. This storage is located outside the main site on a secure hardstanding. Plasterboard is transported by a forklift from the compound to the road outside the blocks under construction. The new boards are lifted on to a scaffold loading bay and carried by labourers along the scaffold and in through doors or windows. A number of boards are stored in the rooms prior to the fixers starting work.

Figure 5 provides a schematic of the capture system at Higher Broughton.

Figure 5 Schematic of plasterboard capture system at Higher Broughton



2.4.1 Capture system considerations:

- Some working practices may make it difficult to establish a single capture system. Working on six houses at a time means that achieving efficiencies in the collection process can be challenging.
- The positive measure of encouraging reuse of board actually makes data collection difficult as labourers are reluctant to move the waste until the work is complete.
- Given the potential problems of data collection on multi-activity sites such as this, it may be possible to get the plasterboard sub-contractor to self-monitor in order to improve the quantity of the data set and potentially the accuracy.
- On this site, three blocks were being boarded simultaneously at different locations on the site. Monitoring each block required more than one person as the waste management operation often occurred simultaneously.

3.0 Lessons learned from site trials during this project

On the basis of the lessons learned during the earlier project regarding the suitability of site characteristics for the use of a chipper, it was decided to focus trials during this project on those sites that offered the most likely costs savings, i.e. high-rise residential sites. This reflects the traditionally high labour costs associated with moving wastes out of these types of construction projects.

All three trial sites fitted the high-rise residential model considered to offer the most potential for positive change:

- Block H, Clarence Dock, Leeds – TWC;
- Blocks C2 and D, Clarence Dock, Leeds – Shepherd Construction; and

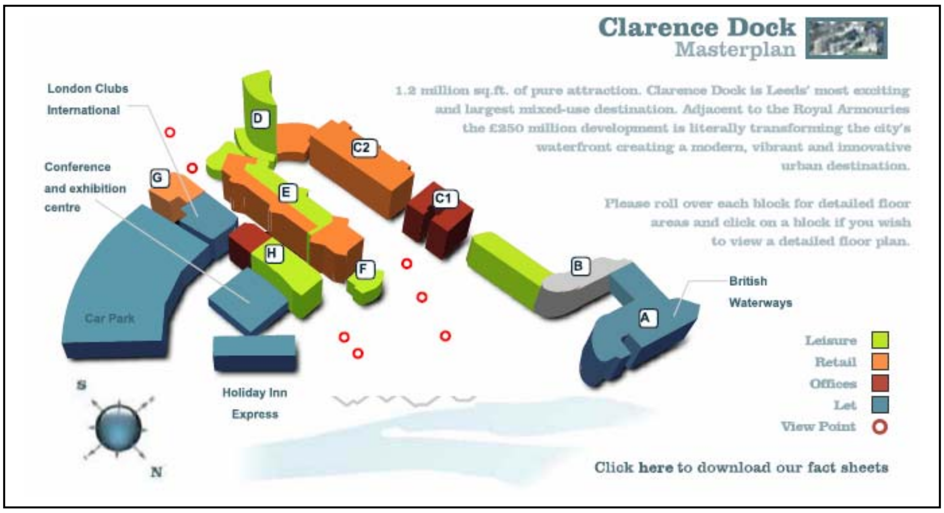
■ King's Place, King's Cross, London – Sir Robert McAlpine.

Summaries of the site trials using the chipper and some of the lessons learned are given below in sections 3.1 to 3.2. These are followed by details of two developments – The Litmus Building, Nottingham, and Bletchley Park, Milton Keynes (sections 3.3 to 3.4) – evaluated as trial sites but dismissed due to a combination of the site and project characteristics that would have made either the savings potential or the ability to implement a new capture system very difficult to achieve. However, these projects offered some important lessons regarding current capture systems and their inefficiencies. They also illustrated how, in some cases, implementing more efficient plasterboard capture systems would result in savings due to the working practices employed on site.

3.1 Clarence Dock, Leeds

Clarence Dock is the largest mixed use development in Leeds (Figure 6). Three blocks of this development participated in trials of the Starke Arvid chipper.

Figure 6 Clarence Dock master plan



Clarence Dock will provide 370,000 sq. ft dedicated to café bars, shops, restaurants, a 131 bed Holiday Inn Express Hotel, 100,000 sq. ft of prime office accommodation, a 50,000 sq. ft London Clubs International Casino and other supporting facilities. A secure, covered car park for 1,650 vehicles is also located on site. The 413 apartments that are already complete are home to an emerging affluent community, who will eventually occupy over 1,100 homes.

The chipper was trialled at three sites in the Clarence Dock development – Block H, Block C2 and the 19-floor Block D tower. Taylor Woodrow Construction is responsible for Block H and Shepherd Construction is undertaking construction of Blocks C2 and D.

3.1.1 Blocks C2 and D – Shepherd Construction

Block C2 (La Salle) has 19,183 sq. ft of retail/leisure and 210 apartments.

Block D (Clarence House) has 25,234 sq. ft of retail/leisure and 228 apartments.

The site footprint for these blocks is relatively small, allowing little space for skips or storage beyond the building footprint. Space located on the west side of the development is being used for the site office compound and skips.

The quantity and rate of plasterboard waste on this development was found to be significant (in the order of 25%). Once the waste has left site, it is transported to a waste transfer station where it is segregated and mixed, according to LSS Waste Management Ltd (www.lsswaste.co.uk), with top soil to form a soil conditioner (Figure 7).

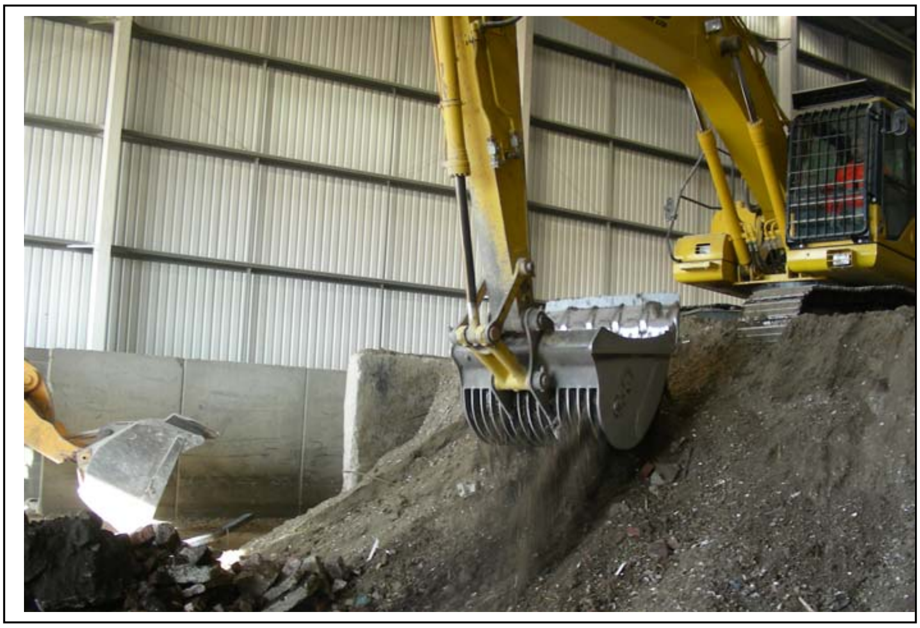


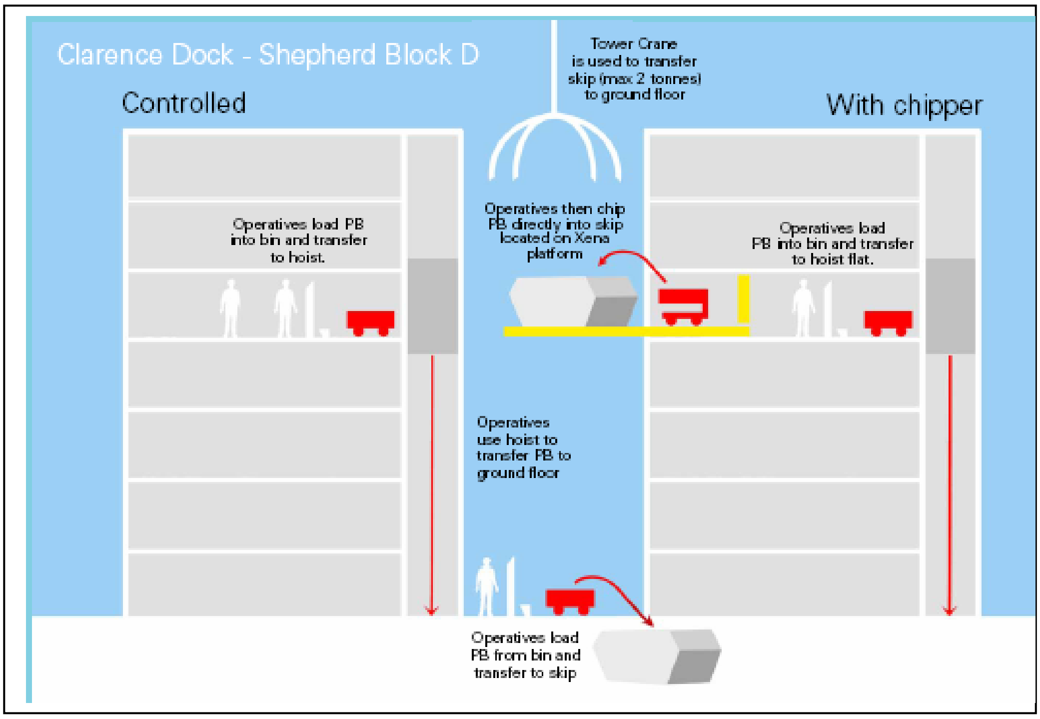
Figure 7 Preparation of soil conditioner at LSS Waste Management Ltd

Unfortunately, the site footprint meant it was not possible to erect a chute on either Block C2 or Block D. This was due to the construction stage of both blocks when the trial began. The decision was taken to trial the chipper using a Xena platform (a retractable landing platform) instead.

The plasterboard capture system (Figure 8) is thus as follows:

- Stage 1: operatives load bins and move to hoist flat initially on floor 11 and subsequently on floor 13 (in response to the progress of the second fix).
- Stage 2: operatives transfer waste from bins and run it through the chipper directly into a skip on the Xena platform.
- Stage 3: once the skip is two-thirds full, it is removed using the tower crane and replaced with an empty skip.

Figure 8 Schematic of plasterboard capture system at Block D, Clarence Dock, with and without chipper



During the site tour, there was a strong contrast in opinion regarding the potential for using a chipper on the site between site managers (strongly positive) and site operatives (very sceptical). It was difficult to establish why this was so; it seemed the site operatives thought of waste and the cost of dealing with it as inevitable while site managers recognised it as an area of opportunity.

3.1.2 Block H – Taylor Woodrow Construction

Block H consists of:

- 131-bed Holiday Inn Express (complete);
- exhibition and conference centre;
- 21,829 sq. ft retail/leisure;
- 22,658 sq. ft offices over five floors (Stanley House); and
- 121 apartments (Cartier House).

The site of Block H is similarly constrained with very limited space for skips at the building footprint. Current practice is to place skips on the eastern site boundary where access is easiest. Unfortunately this is also the furthest point from the source of the waste. Therefore the waste is transferred from bins to tipper skips at the ground floor of the building and these are then transferred to a 40 cu. yd skip at the site boundary, resulting in triple handling of the material.

During the site visit, a test was carried out to see whether it was possible to place a 20 cu. yd skip on the western site boundary adjacent to the apartment building. A successful test established that this skip could be used to erect a chute on the development linked to the chipper. Figure 9 provides a schematic of the plasterboard capture system with and without the chipper.

The quantity of plasterboard waste at this site was estimated to be 5,100m^2 (10%). This was much less than that from Blocks C2 and D because Block H contains half the number of apartments than the other two blocks. However, there was more than enough waste to undertake a reasoned trial of the chipper.

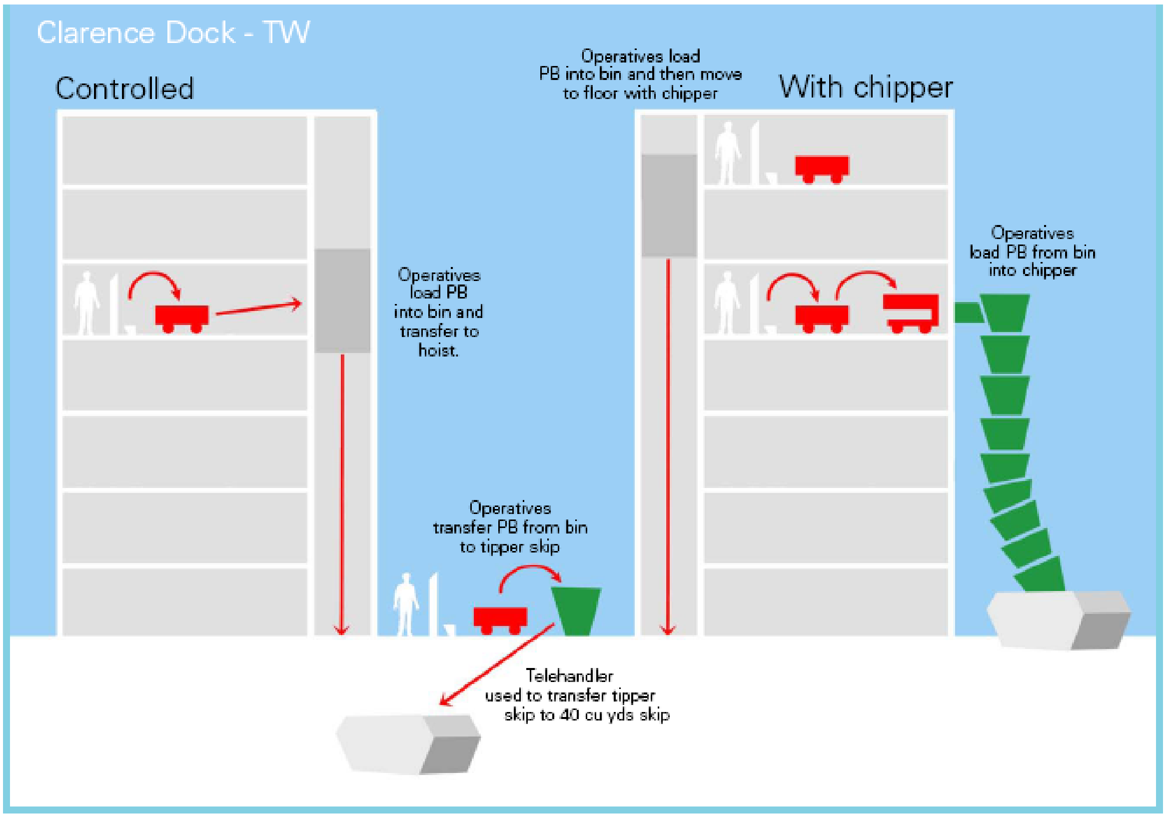
The plasterboard waste on this site was removed using British Gypsum's Plasterboard Recycling Service. This allowed accurate data capture of the quantities and rates of waste on this site (skip data were provided by British Gypsum).

The erection of a chute and the use of the Starke Arvid waste bins facilitated a significant reduction in both labour costs and the skip volumes required to dispose of the plasterboard waste on this block (see section 5.3.3).

3.1.3 Capture system considerations

- It is essential to plan for the adoption of a plasterboard capture system early on in the project. Decisions made at the beginning of the contract (such as the design of the scaffolding) made it impossible to operate the most efficient means of plasterboard capture on Blocks C2 and D.
- In order to achieve buy-in for a plasterboard capture system, it is preferable to implement the most efficient system from the start rather than proceed with iterations. Resistance to change of practice was witnessed frequently throughout these trials.
- Despite possessing a very small site footprint, Block H managed to accommodate a 40 cu. yd skip adjacent to the building (see front cover photo) which, with the provision of a chute, offered the best economic and environmental savings.
- Double-handling of plasterboard waste appears to be standard practice. Constant reinforcement of a more efficient approach is required in order to stimulate change.

Figure 9 Schematic of plasterboard capture system at Block H, Clarence Dock, with and without chipper



3.2 Kings Place, Kings Cross, London

During the later stages of this study, an opportunity arose to trial a bespoke plasterboard capture system from the beginning of the construction project. As noted above, this offers an important advantage in ensuring buy-in for a capture system and allows for the inclusion of key elements of best practice such as chutes.

King's Place consists of a seven-storey office development, a major new arts venue (including a 420-seat conference hall), art galleries, waterside restaurants and a bar located 150 metres from King's Cross railway station. The project is being managed by Sir Robert McAlpine and employs MPG Contracts Ltd as the dry lining contractor for the development.

Starke Arvid had already contacted MPG Ltd regarding the promotion of its chipper and auxiliary tools (trestles, bins, etc). After further inspection of the King's Place development, it was decided it provided an ideal site for trial due to the following favourable factors.

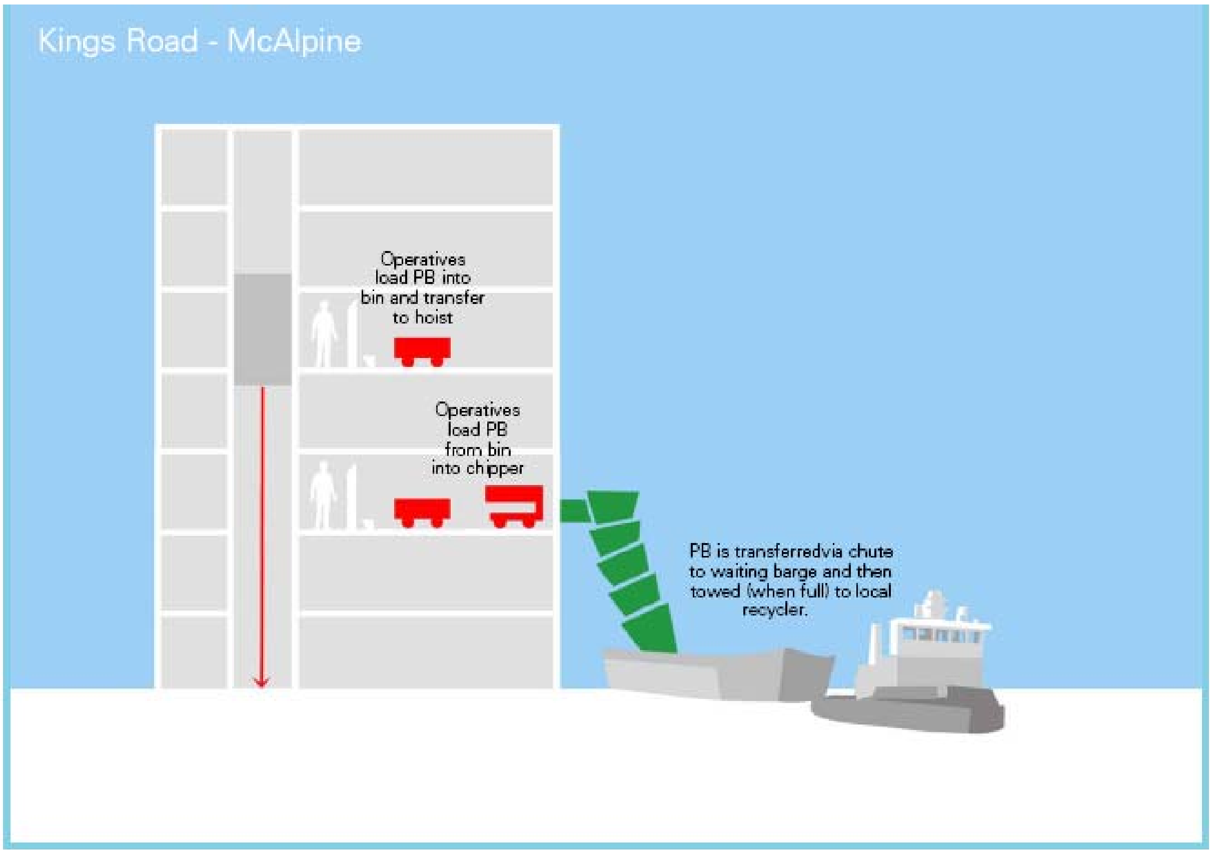
- The site was still in the early stages of construction and therefore offered the potential to tailor the plasterboard capture system to suit.
- The site management (both from Sir Robert McAlpine and MPG Ltd) were proactive in identifying innovative approaches to plasterboard capture and were receptive to the idea of the plasterboard chipper. As noted previously, site buy-in is crucial to ensuring successful development and management of a best practice capture system.
- The project was large enough to ensure investment in establishing a best practice plasterboard capture system and to realise its savings.

MPG Ltd was the main architect of the plasterboard capture system, with support from Sir Robert McAlpine and Starke Arvid. Taylor Woodrow was only involved in reviewing the site from the perspective of this study.

Figure 10 provides a schematic of the capture system developed for the trial at King's Place. The system makes use of the proximity of the site to the Battlebridge Basin off Regent's Canal to remove the waste plasterboard by barge. The barge is operated by Wood, Hall & Heward Limited (which also provides barges bringing materials to

the site) and the recycling company is Powerday plc (www.powerday.co.uk), whose materials reclamation facility (MRF) at Old Oak Sidings in north London is next to the Grand Union Canal.

Figure 10 Schematic of plasterboard capture system at King's Place



3.2.1 Capture system considerations

The following are considered specific positives for this site.

- Establishing a best practice plasterboard capture system at the beginning of the project helped to ensure an appropriate level of support and to ease its implementation on site.
- The high level of support for the plasterboard capture system resulted in stronger economic benefits for the site.
- The use of a barge over road haulage to transport the waste plasterboard away for recycling yields environmental and economic benefits.

3.3 The Litmus Building, Nottingham

The Litmus Building (Figure 11) forms Phase 1 of the larger Litmus Project, which will be the largest residential new-build project of its type to be built in Nottingham.

The complex is being built on an important site within Nottingham's Eastside regeneration zone and is the largest new build apartment complex of its kind in the Midlands. The Litmus Building features 296 one- and two-bed apartments, all with balconies or terraces, with multi-level basement car parking, a gymnasium, a pool, sauna, steam rooms and a 24-hour a day concierge reception. The development stands 13 floors tall.

The main contractor on this development is Laing O'Rourke and the dry lining subcontractor is Reynolds Building Systems. Both companies support the objectives of the WRAP research project.

The unique feature of this development compared with the Clarence Dock development is that the dry lining sub-contractor is responsible for waste management on the project and therefore not only has an incentive to reduce waste but also an incentive to handle it in the most efficient manner.

Figure 11 The Litmus Building, Nottingham

3.3.1 Capture system considerations

- The site footprint is restricted and extends no more than 10 metres from the building footprint at its widest point (the western boundary). Space for skips and materials is therefore limited. However, Reynolds had negotiated enough space for a 40 cu. yd skip (although this was not being used).
- The quantity and rate of plasterboard waste on this development was significant despite the understandable adoption of measures to reduce the quantity of waste. These measures include the use of custom-sized boards and a revised door detailing[1] which, it is claimed, has saved as much as five full boards per floor in plasterboard waste.
- The plasterboard waste is removed from site in 800-litre and 660-litre bins in batches of 10. One bin is placed on each working floor. Once filled, they are transported to the ground floor using the hoist and collected by the waste management contractor, Ward Recycling (www.wardrecycling.com).
- It was not possible to erect a chute as there was nowhere to attach it to the side of the building and no space at the building footprint to place a skip. The perception of the supportive site management was that the chipper would provide sufficient volume savings to outweigh any additional labour costs associated with its operation.
- The current plasterboard capture system presented some significant health and safety risks through the need to push heavy 800-litre bins full of plasterboard waste up a 45° slope to the hoist. This required 2–3 labourers.

3.4 Enigma at Bletchley Park, Milton Keynes

This housing development (Figure 12) under construction by Taylor Woodrow Developments is part of the historic Enigma site.[2] Unfortunately, the many different sources of plasterboard waste (one per house) made the siting of the plasterboard chipper an impossible task without adding to the time spent dealing with the plasterboard waste (which is often the most expensive factor). In addition, the much slower pace of construction meant that there was not the same need to deal with the plasterboard waste so efficiently – and time could be spent breaking up the waste board before placing it in the British Gypsum bags.

[1] *Knauf Eco-Jamb*

[2] *See www.bletchleypark.org.uk*

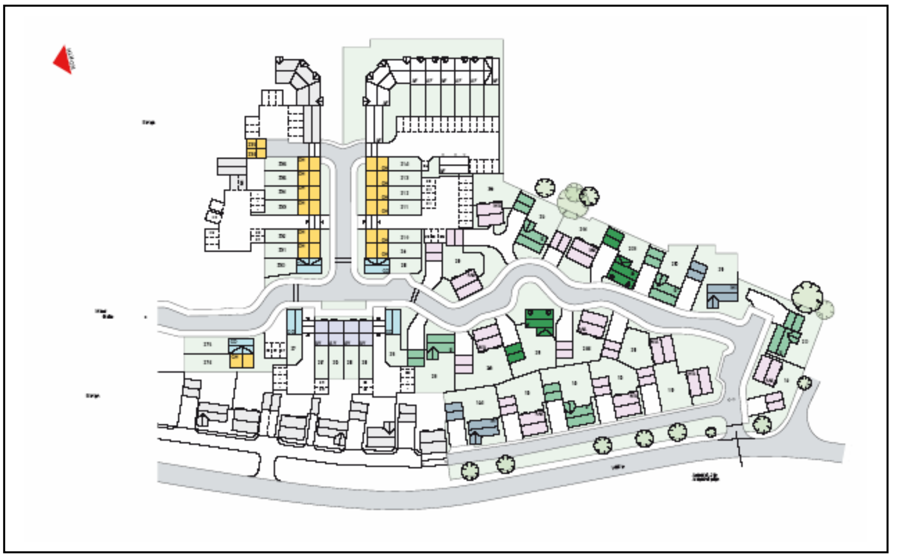


Figure 12 Bletchley Park site plan

3.4.1 Capture system considerations

- Managing more than one source of plasterboard waste across a wide area such as that of a housing site will require more than one chipper. In these cases, each source will need to produce the required minimum amount of waste board to make the capture system effective.
- The rate of boarding at a housing site may be insufficient to provide an acceptable payback on the use of a chipper.
- Power constraints on a housing site (where power is often not available until much later in the project) may make the use of a chipper impractical.

4.0 The Starke Arvid plasterboard chipper

The machine (Figure 13) is designed specifically to reduce the bulk of waste plasterboard. It does this by reducing the waste plasterboard into manageable pieces, thereby increasing the volume that can be placed in waste containers. Two counter-rotating cylinders with blades cut the board and feed the waste pieces from the machine ready for collection.

Figure 13 Starke Arvid plasterboard chipper

The machine is designed to chip most types of plasterboard from 9.5 mm to 19 mm, with the exception of thermal laminates and, depending on the site's recycling requirements, possibly also foil-backed plasterboards.

The rate of plasterboard through the machine is geared to 25 metres per minute. Throughout the trials, it was observed that the limiting factor on the rate of plasterboard that can be chipped by the machine is the labour required to feed the plasterboard rather than the gearing of the machine.

Assuming the use of standard wall board (2,800 × 1,200 × 15 mm), the chipper could physically process at a rate of 0.45 m^3/ minute. The fastest rate of plasterboard capture observed during the project (the Wastecycle trial using a 8 cu. yd skip; see section 1.4) equated to 0.067 m^3/ minute.

Successful use of the plasterboard chipper requires adequate provision for effective training of the workforce. This should involve coaching operatives in:

- the methods used to collect the waste;
- the equipment they use; and
- how they should plan their work flow.

Such training helps to achieve significant efficiency gains over and above the simple volume improvements in the waste containers. It is a misconception that this kind of machinery can be a 'plug in and use' solution to the waste issues presented on construction sites.

Other Starke Arvid products (e.g. board handling trolleys, trestles and waste bins) complement the whole concept of efficient material movements – be that products in or material waste out of the building. These gains can be achieved only by getting closer to the customers, understanding individual site situations and offering effective solutions.

The User Manual supplied by Starke Arvid for the chipper is reproduced in Appendix 1.

4.1 Instructions on chipper use

TWC issued a method statement (Figure 14) on the use of the Starke Arvid chipper at its construction site at Clarence Dock, Leeds. These instructions were based on the User Manual produced by Starke Arvid (see Appendix 1).

Figure 14 Method statement issued by TWC for the Clarence Dock site trial

Ref: TWC01/HBS
Date: 14.01.07

Starke Arvid Chipper@ Taylor Woodrow Construction site, Clarence Dock, Leeds

MACHINE DESCRIPTION
This machine is designed specifically to reduce the bulk of waste plasterboard.

It does this by reducing the waste plasterboard into manageable pieces therefore increasing the volume that can be placed in waste containers. Two counter-rotating cylinders with blades cut the board and feed the waste pieces from the machine ready for collection.

The machine is designed to chip most types of plasterboard from 9.5 mm through to 19 mm with the exception of thermal laminates and, dependant on the site recycling requirements, possibly foil-backed plasterboards.

Note: Information contained within this method statement should be used in conjunction with the chipper User Manual and practical training issued to operatives on site.

TAKING DELIVERY AND MOVEMENT OF CHIPPER

Deliveries are usually made by a small truck (maximum 7.5 tonne vehicle). Unloading will be in the form of forklift, mechanical self-off load (hi-ab) or by hand. Guidance notes for the correct lifting/slinging of the chipper are contained within the user manual.

Deliveries of chippers will be scheduled to main contract programme requirements. The chippers are generally delivered banded/shrink wrapped on a timber pallet.

GENERAL SAFETY RULES

Operation of the chipper is to be carried out in accordance with current health & safety regulations and practical common sense. Please read and adhere to the guidelines set out in our user manual.

Guards

- The machine is equipped with a cut-out switch in the cover that will automatically stop the machine if the lid is opened during operation.
- The machine is installed with an emergency stop switch that should be struck in the event of an emergency.
- The in-feed has a protection that is designed to prevent operatives from placing their hands within the machine.
- The scrap outlet has a protection that is designed to prevent operatives from placing their hands within the machine.
- **Do not** attempt to modify, alter or tamper with any of the guards or electrical safety devices in any way.

General safety rules (continued)

- For plasterboards only; other materials could damage yourself as well as the machine.
- The machine is equipped with rotating blades. Do not insert hands or other foreign objects.
- Only authorised personnel should use the machine.
- To immediately stop the machine, strike the red ‘emergency stop’ button. Reset using the safe operation key.
- Keep the work area clean to avoid risks of slips, trips and falls.
- Ensure the braked wheel is engaged to prevent unnecessary movement when the machine is in operation.
- Ensure a reasonable workspace area to ensure safe operation for you and other personnel.
- Never leave the machine running unattended.
- When lifting the chipper, ensure the correct straps are used and are placed correct position.
- Metal to metal contact with the rotating blades could significantly reduce chipper performance as well as causing permanent damage to the chipper. Ensure no screws or foreign objects are embedded in the waste plasterboards.

MACHINE OPERATION

1. Locate the chipper on flat, even ground as near as practical to a 32 amp site transformer to reduce the length of extension cable to minimise voltage drop and gain the maximum power from the machine.
2. Choose a suitable collection method.

(a) If filling directly into large waste skips, place chipper at the open ends of skip.
(b) If filling 1 tonne (dumpy type) waste sacks, support the sides of the bags with adequate framing or use recommended Starke Arvid bag supports.
(c) When using Starke Arvid waste bins, operate the machine with the stand in the lower position. This will also improve the ergonomic operation of the machine.

4. Apply the brake on the locking wheel to prevent unnecessary movement.
5. Turn on the machine by pressing the green ‘Start’ button. The rotating blades will start and the machine is ready to use.
6. Ensure that only clean waste plasterboard is used with the machine ensuring it is free form screws, metal or other contaminants.
7. When chipping longer pieces of board, support the board by hand until it can support its own weight.
8. The machine is capable of chipping boards up to 700 mm wide.
9. To stop the machine, press the red ‘Stop’ button.
10. In the event of a material blockage, follow procedure laid down in the User Manual

UNLOADING and DISTRIBUTION

Unloading and placement of the chipper can be by either mechanical offloading facilities or by hand. The chipper must be stored within a secure compound area for security.

REMOVAL OF WASTE

Do not allow waste to build up around the chipper. Follow standard housekeeping procedures to maintain a safe working environment. **NOTES**

4.2 Technical development of the chipper during the project

The early stages of the site trials using the chipper enabled Starke Arvid to carry out some excellent evaluation and development work. Long-term site exposure identified areas for improvements and highlighted modifications required to improve site performance, prevent blockages and improve the operative training programme. Previous trials in a controlled environment had shown the suitability of the chipper's basic design, but further exposure to site behaviour and capture systems highlighted a number of issues (Table 4).

Table 4 Chipper issues and solutions highlighted by the site trials

Problem	Solution
Waste paper and board debris building up and causing jamming in the waste out-feed Boards such as soundbloc are manufactured from a paper liner with several plies. If the operatives snap the board by hand and rip it apart, they produce long lengths of liner as well as irregular board pieces which, when chipped, cause considerable debris. This debris has a tendency to build up inside the machine.	Manufacturing a modified waste out-feed collector allowed the majority of paper offcuts to fall clear from the machine. Incorporating in the training procedure a requirement for operatives to: ■ periodically clean the out-feed; and ■ simply tear away the larger pieces of paper and place them directly in the skip.
Synchronisation of the drive belts During the early stages of the project, it was noticed that the cutting cylinders were going out of synchronisation. Initially it was thought that the bushes that connected the belts to the drive shafts were slipping. However, it was deduced that the bolts that attach both the cutting cylinders to the chassis were insufficiently tightened to cope with the torque generated during the chipping process.	Re-tensioning the drive assembly cured the problem and this issue did not re-occur on any sites for over a month. In full production of the chipper, Starke Arvid plans to use the higher specification Kevlar-based drive belts, which offer a superior performance.
Revision of out-feed to ensure function and conformity with CE requirements The original out-feed design needed to be modified to conform to CE requirements, i.e. to prevent the potential for an operative to touch the cutting cylinders from the out-feed of the chipper.	The initial solution proved to be unreliable (due in part to the debris build-up noted above). The second solution incorporated some steel fingers which prevent operatives from placing their fingers in the back of the machine and keeps the board pressed against the bottom of the waste out-feed, thus preventing any blockages. This appears to be an excellent solution and has been retrofitted to each machine on the trial with positive results.
Reverse button ineffective In the unlikely event of a jam in the rollers, the reverse button was installed to offer an easy way to remove any jammed plasterboard. However, it was discovered that the characteristics of 110 volt site power mean that insufficient torque from the motor is generated from a standing start to effectively unblock the jam.	Starke Arvid intends to install a capability to manually reverse the cylinders by using a crank handle in the drive unit. It will only be possible to do this with the chipper safely isolated. Internal discussions are underway about the need to retain the reverse switch, as it remains useful for the cleaning of the scrap-out feed.
Site power supply:32 amp versus 16 amp Although the machine draws less than 16 amp when in	Minimising the length of the power cable and

Problem	Solution
operation and has in fact a safety trip switch rated at 15 amp, the site trials suggest that a 32-amp power supply is required on site to ensure a supply of good quality power.	ensuring that it has a minimum thickness of 2.5 mm^2 should minimise any power drop along the cables.
Material build-up on waste chutes On sites using waste chutes, there was a need to ensure: ■ the waste chutes are set at the correct angles; and ■ they are set up in a way to prevent the chipped boards creating a blockage.	Starke Arvid intends to look into a chute adapter to offer the best interface between the machine and the waste chute.
Dust generated from waste chutes On sites using waste chutes, there was a need to minimise the dust generated when chipped boards fall down the chute.	The situation is improved by: ■ reducing the overall chain length of the chute sections; and ■ where practical, covering the waste container.

4.3 Proposed route to market for the chipper

During the last few months of the trials, Starke Arvid made a number of decisions regarding the future of the machine.

- Initially, sales would be directly to the market. Depending on site situations, Starke Arvid expected the sub-contractor or possibly the main contractor to be the purchaser of the equipment.
- Starke Arvid planned to achieve effective selling through demonstration of the various solutions as well as offering on site support and coaching. New sales would involve a minimum of half a day of on site practical training with further follow-up visits.
- The initial target market would be the top 20 dry lining sub-contractors in the UK (particularly on larger format projects).
- The cost of each machine would be £3,450 + VAT (delivered and including half a day of on site training).
- The first production series would arrive in the UK by mid-June 2007, with additional volume arriving after the Swedish holiday period. By October 2007, the machine was in its fourth or fifth production series.
- The aim would be to sell 50 units by December 2007.
- Additional technical support personnel would be recruited to provide additional sales support and on site training. A technical support manager started work on 1 September 2007.

5.0 The economic business case

The cost of dealing with plasterboard waste is the principal driver for dry lining subcontractors when assessing capture systems. It is known that managing plasterboard waste can be costly and reducing these costs is a significant incentive for the sub-contractors.

The aim of this economic analysis is to identify the savings from a more efficient system in order to establish the business case for that system.

The main factors within the capture systems identified as having potential cost savings are:

- labour costs;
- running costs of the system; and
- disposal costs of the plasterboard waste.

To compare plasterboard capture systems with and without a chipper, it was necessary to collect data on both existing and new systems. Collected data included:

- time spent using the system and the associated cost;
- weight of waste in the skip and the costs of its disposal; and
- cost of equipment hire.

The data were analysed and a rate of cost per cubic metre was calculated in order to allow comparisons between sites. The assumptions made are given in Appendix 2.

For comparison, the systems were split into three stages:

- **Stage 1:** Collection of plasterboard waste into bins.
- **Stage 2:** Movement of waste from source floor to ground floor, or access point if chute is used.
- **Stage 3:** Movement of waste into final receptacle.

5.1 Labour costs

The time that labourers spend moving the plasterboard waste is a significant proportion of the capture systems currently employed. Movement of the waste from the source to the skips involves repeated journeys with large, often heavy bins through routes that are sometimes difficult to access. Reducing the time that the labourers spend moving the waste will reduce:

- the labour cost of the system; and
- the physical effort of moving the bins.

The analysis showed that savings can be made at each stage.

5.1.1 Stage 1

If fixers place the waste directly into the bins, the need for labourers for this stage is eliminated and the cost incurred can be saved.

For the Shepherd Clarence Dock site, this cost was calculated to be £6.98/m^3 (Figure 17).

5.1.2 Stage 2

The use of the chipper and chute for stages 2 and 3 removes the requirement for labour to manually break and move the waste to the receptacle.

For the Aylesbury site, the labour cost saving was calculated to be £12.51/m^3 (Figure 16).

For the TWC Clarence Dock site, the saving was calculated to be £8.35/m^3 (Figure 18), as use of the chipper also eliminated Stage 3.

5.1.3 Stage 3

This stage is eliminated by systems that utilise a chute directly into a skip.

The Wastecycle trial compared the manual and chipping filling of plasterboard bags.[3] The saving due to chipping into the bags was calculated to be £13.69/m^3 (Table 5).

The Shepherd Clarence Dock site chipped directly into the skip compared with manually emptying the bins. This still required the movement of the bins or skip to the ground floor. The cost of chipping was £0.74/m^3 more than manual handling (Figure 18).

The preferred capture system is to utilise a chipper and chute to transfer the waste from the source floor directly to the receptacle. This removes the need to manually handle plasterboard waste between floors and into the receptacle.

5.2 Waste management

Waste plasterboard has a variety of end uses. The actual end use is often determined by factors such as:

[3] *During this, four labourers (for the purpose of speed) were employed to break up the plasterboard and fill the British Gypsum bags. This is not anticipated to be standard practice.*

- the site location;
- the space available; and
- supplier agreements made with the waste management contractor.

The waste receptacle on each site will vary according to the site conditions and the end use requirements for the plasterboard waste, e.g. barge, bins, bags or skips. There is limited scope in this project for reducing the cost of the different receptacles however there is potential to increase the quantity of waste in each receptacle.

The quantity of plasterboard in a 40 cu. yd skip at the TWC site at Clarence Dock was calculated to range from 35% to 47%. Through utilising a chipper, the percentage of plasterboard in a skip increased to an average of 63.3% (based on average of weighed skips). This was calculated to provide a saving of:

- £22.76/m^3 for an 8 cu. yd skip;
- £11.22/m^3 for a 35 cu. yd skip; and
- £25.07/m^3 for a 40 cu. yd skip.

Controlled trails carried out at Wastecycle (see section 1.4) compared the volume of plasterboard that was captured in a British Gypsum bag with a manual system (0.35 m^3) and when using a chipper (0.48 m^3).

Both the TWC site at Clarence Dock and the Wastecycle trial achieved a significant improvement in the efficiency of waste being placed in the skip and therefore a saving in skip costs. This is also evident visually in Figure 15, which shows better compaction of the plasterboard.

If the average calculated compaction is achieved, the weight of plasterboard in a 40 cu. yd skip will be 15.2 tonnes. This means that the single axle lorries (reported maximum lift of 16 tonnes) that remove the skips are able to lift the skip. If the weight of plasterboard increased to over 16 tonnes, this problem can be overcome by removing the skips with a double axle lorry (reported maximum lift of 32 tonnes).

Figure 15 Difference in compaction between chipped and un-chipped plasterboard

The chipper system reduces the size of the plasterboard waste to 140 × 100 mm pieces. This increases the amount of plasterboard waste that can be put in each receptacle because the smaller pieces fit into it with less air voids. The percentage amount of plasterboard in the receptacle (i.e. the volume of the receptacle occupied by the waste) is therefore increased.

When skips are left susceptible to rain, the plasterboard can absorb moisture and gain in weight. During the Aylesbury trial (see section 2.3), the weight of a British Gypsum bag was found to have increased by 10% (24 kg) after one night in the open air (without prolonged rain). This makes the bag more costly to dispose of and can easily be prevented by covering the skip. This also reduces the risk of any dust produced becoming a nuisance.

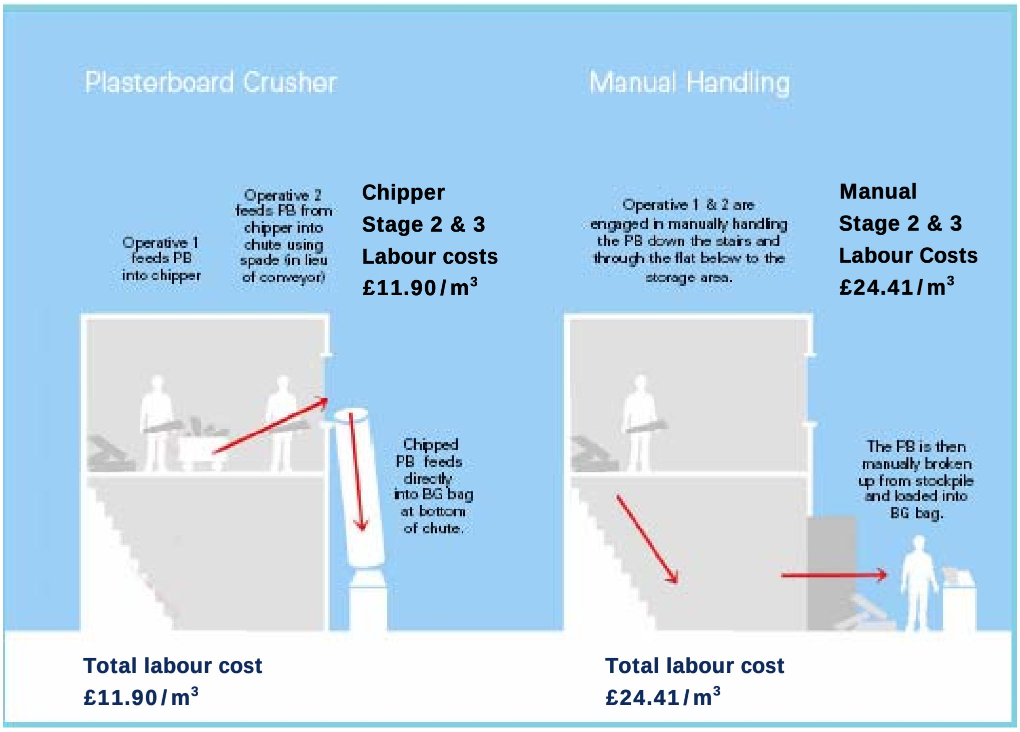
5.3 Economic site schematics and savings

The savings calculated for each stage of the plasterboard capture systems at four trial sites are summarised in Figures 16–19. These schematic diagrams highlight the differences in systems employed on site and the costs at each stage.

5.3.1 The Square at Grand Central, Aylesbury

This trial was carried out using the chipper developed by Optimum Recycling Systems and not the Starke Arvid chipper. See section 2.3 for details of the site and the plasterboard capture system employed in the trial.

Figure 16 Economic schematic for The Square at Grand Central, Aylesbury

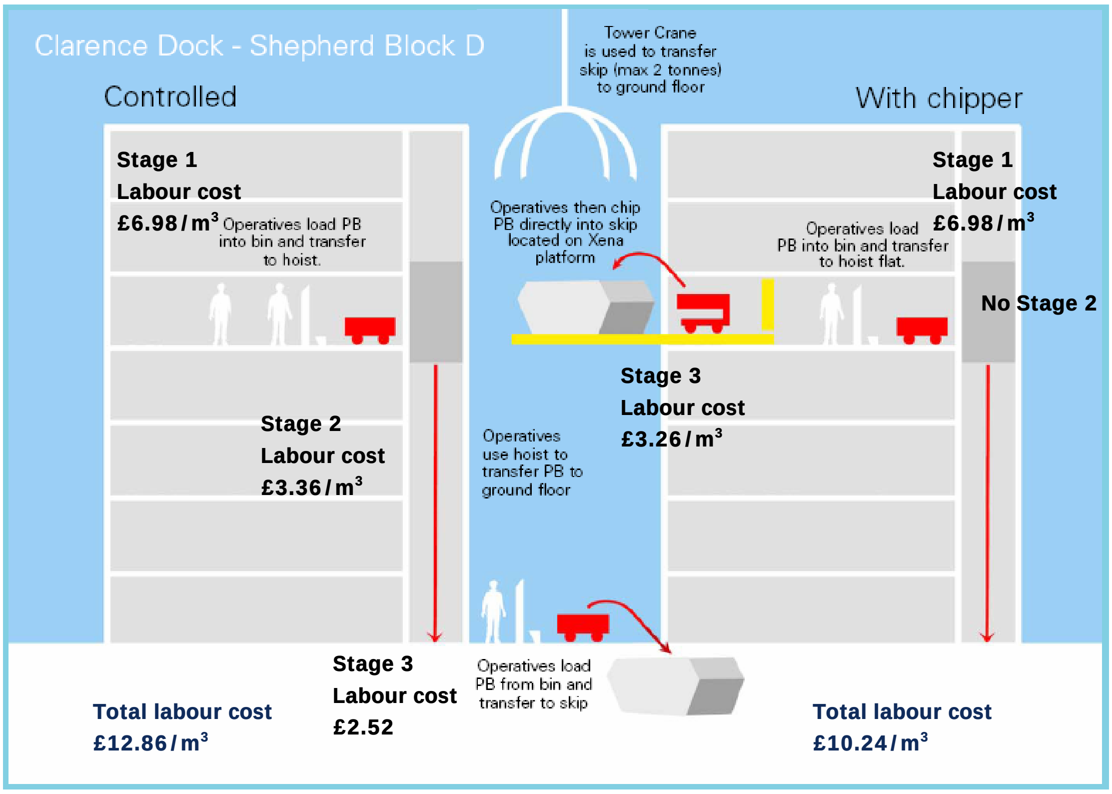


- Use of the chipper results in a 51% saving in labour costs. This saving is likely to be much higher had the trial taken place on level 3 rather than level 1; however, the schedule of works made this impossible to achieve in the time frame available.
- Given the conservative estimate of waste per plot and the lack of accounting for wasted time/fatigue in the calculations, these figures should be considered a worst case scenario if no hoist or tower crane is available to support the removal of plasterboard waste from the building.
- It is clearly uneconomical to manually handle plasterboard waste from a building even if it is only from the first floor.
- This capture system was less economical than later ones studied due to the nature of the construction. This was a housing site where the rate of construction (and plasterboard waste generation) was a lot slower than on some of the later trials. This meant that less of a collection system was set up and the process of manually handling the waste out of the building was more complicated than if a planned route had been established.
- The British Gypsum bag was unsuited to the chute and time was lost unblocking the chute where it had backed up (due to there being less space for the plasterboard chips to spread out).

5.3.2 Clarence Dock – Shepherd Construction

See section 3.1.1 for details of the site and the plasterboard capture system employed in the trial.

Figure 17 Economic schematic for Shepherd Construction site at Clarence Dock, Leeds

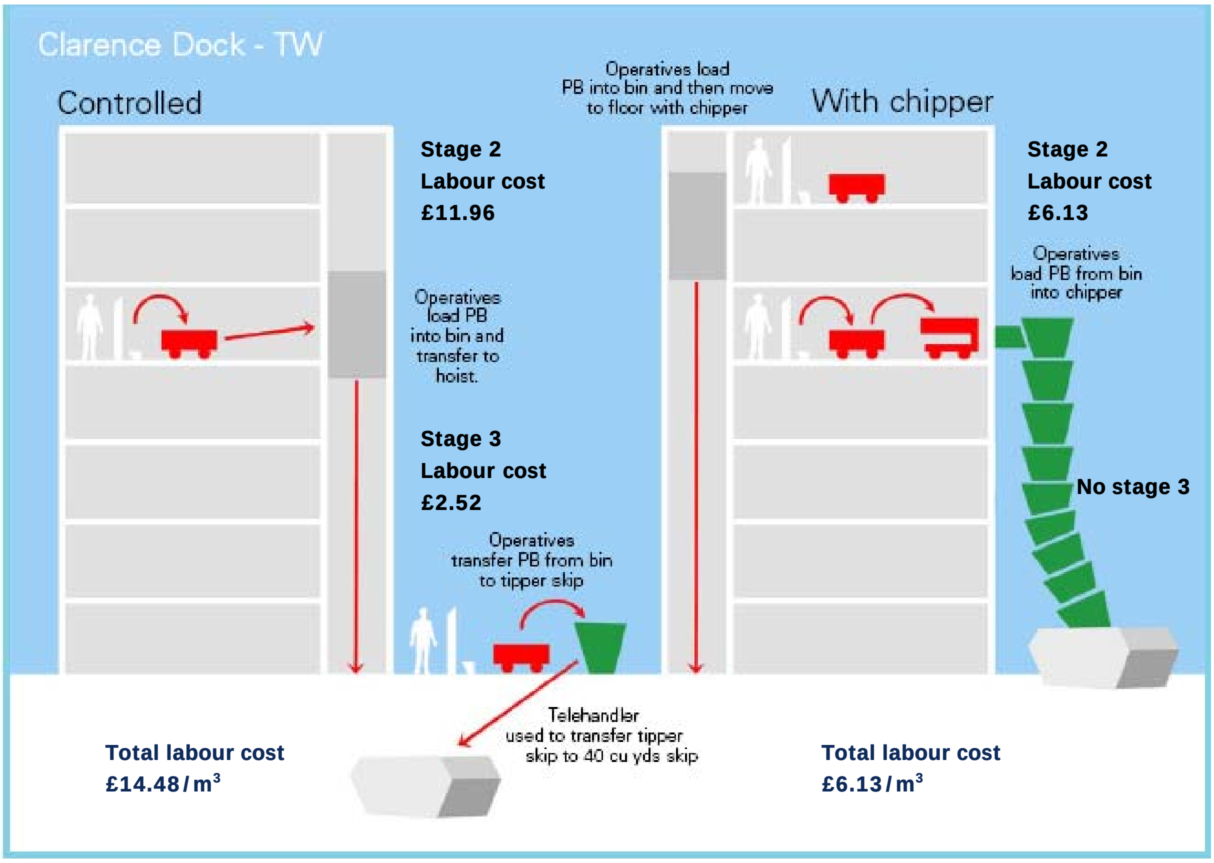


- The difficulty encountered in erecting a chute on this project reduced the potential savings significantly. The alternative of using a Xena platform was relatively effective when in operation, but there were difficulties in securing both crane time and ensuring a consistent supply of plasterboard in the hoist flats. These factors reduced the efficiency of this system.
- The narrow corridors in Block D meant that it was not feasible to use bins to collect the waste. This meant that the fixers could not contribute to the process by placing their waste in the bins and all the plasterboard waste had to be manually handled to the hoist flat. This was a major cost and could not be reduced through the use of a chipper.
- The trial on Block C2 (operating an identical means of plasterboard capture) identified a significantly improved saving at Stage 3 (£1.74/m^3). This can be attributed to a more consistent supply of plasterboard – on all but one occasion, a full skip of plasterboard was chipped in one go. This is not likely to be representative of site practice and meant it was difficult to achieve reliable data on Stage 2 for this project. As a result, these data were not included in the economic analysis.

5.3.3 Clarence Dock – TWC

See section 3.1.2 for details of the site and the plasterboard capture system employed in the trial.

Figure 18 Economic schematic for TWC site at Clarence Dock, Leeds

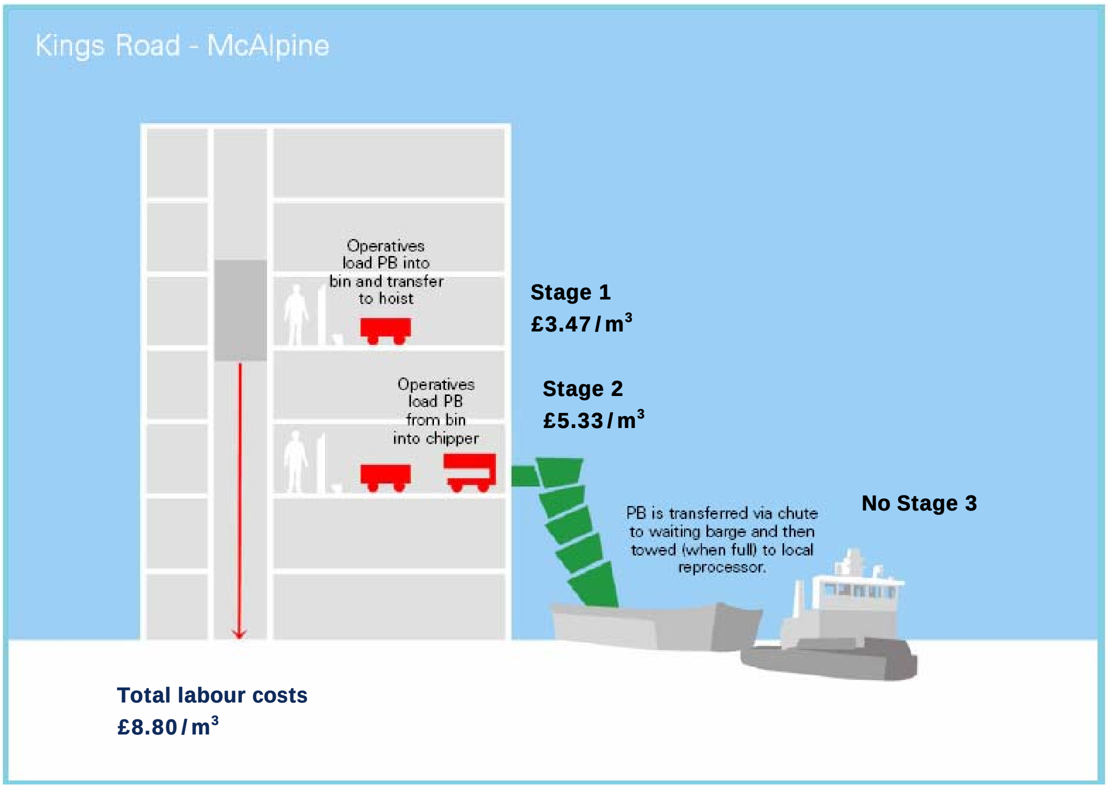


- The instruction by site management that the fixers should fill the bins rather than the labourers removed Stage 1 in the process. This saved an average of £6.98/m^3 compared with the Shepherd Clarence Dock site.
- The use of the chute eliminated the need to manually transport the material to the ground floor and thereafter sort into the appropriate skips. This proved the most significant saving (over £8/m^3), but was only possible through use of the chipper.
- The easy access to the chute via the hoist flat was one of the main reasons for the large saving on this project. The high level of utilisation of the hoist meant that waiting times under the manual handling system were often long and unpredictable; this problem was removed through the use of the chipper and chute.
- The other main efficiency saving was achieved through the placing of a skip adjacent to the footprint of the building. A chute could then be fed directly into the skip rather than operating a manual handling system that involved feeding the waste from bins into the tipper skips and then these using the forklift to tip into the 40 cu. yd skip.

5.3.4 King's Place

See section 3.2 for details of the site and the plasterboard capture system employed in the trial. Figure 20 shows the chute discharging directly into the barge moored in the adjacent Battlebridge Basin off the Regent's Canal.

Figure 19 Economic schematic for King's Place, King's Cross



- The site at King's Place benefited from early implementation of the capture system, although it took longer than expected to generate a sufficient quantity of waste (a positive sign from a waste minimisation point of view).
- The efficiency of this capture system was supported significantly by the chute (labour costs) and the barge (disposal costs). However, even within this system there were areas for improvement. For example, the decision to stockpile the plasterboard waste next to the chipper rather than just leave it in the bins introduced a degree of double handling in this system. This was due to a lack of bins on the site.
- In general this system proved very efficient. When compared with the capture system at the Aylesbury site, it is clear that there are significant benefits in planning such systems up front.

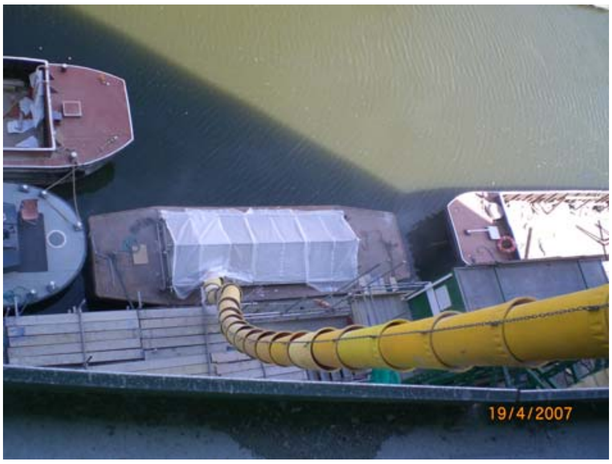


Figure 20 Chute into barge at King's Place

5.3.5 Summary of economic results

To show the cost versus savings for a chipper system, the labour cost and the waste disposal costs were combined for the TWC Clarence Dock site. This was the only site for which site-specific and suitable waste disposal costs were available. Use of the chipper resulted in a 47% saving on total costs for this project (Table 5).

Table 5 Comparative costs of manual handling and use of a chipper at TWC Clarence Dock

Cost element	Manual (£/m^3)	Chipped (£/m^3)	Saving (£/m^3)
Labour	£14.48	£6.13	£8.35
Waste	£56.00	£30.99	£25.01
Total	**£70.48**	**£37.12**	**£33.36**

Table 6 summarises the economic results for these four sites together with those from St James Apartments, Cheltenham (see section 2.2) and the Wastecycle trial (see section 1.4). The Wastecycle calculations are shown in Tables A12–A14 in Appendix 2.

Table 6 Economic results summary

Project	Stage	Type of system	Cost per m^3	Saving	Comments
St James Apartments, Cheltenham	3	Chipper	£3.52	No data	
The Square at Grand Central, Aylesbury	2 & 3	Manual	£24.41	£12.50	
		Chipper	£11.90		
Shepherd Block D, Clarence Dock	1	Manual	£6.98	No data	
	2	Manual	£3.36	No data	
	3	Manual	£2.52	–£0.74	Chipper removes Stage 2. Stages 2 & 3 manual together cost £2.62 more than use of chipper.
		Chipper	£3.26		
TWC, Clarence Dock	2	Manual	£11.96	£8.36	
	3	Manual	£2.52		Assumed from Shepherd site at Clarence Dock
		Chipper	£6.13		Removes Stage 2
McAlpine, Kings Cross	1	Chipper	£3.47	No data	No control data
	2	Chipper	£5.33		
	3	Chipper	£0.00		
Wastecycle trial	3	Manual bags	£20.15	£13.69	
		Chipper bags	£6.46		
		Chipper skip	£6.20	No data	No control data

Based on these results, it is possible to calculate the total cost savings for a certain size of skip and therefore the payback period at which the savings would exceed the cost of purchasing the chipper and the chute. This payback period is shown in Table 7 for the three sites for which comparable data are available. Comparable data are not available for the King's Place site.

Payback is given as the number of skips taken away before the use of the chipper becomes viable. It is determined by dividing the capital cost of the chipper and the chute by the total saving per skip. The capital costs varied between projects depending on the capture system – primarily whether a chute was used as well as a chipper.

Table 7 Economic payback in terms of skips

Project	Stages	Skip size (cu. yd)*†	Cost saving (£/m^3)			Total saving per skip (£)	Payback (skips)
			Labour	Waste	Total		
The Square, Aylesbury**	2 & 3	LSS 8	12.50	22.76	35.26	215.78	30
		LSS 35	12.50	11.22	23.72	634.75	10
		British Gypsum 40	12.50	25.07	37.57	1,148.91	6
TWC Clarence Dock**	2 & 3	LSS 8	8.36	22.76	31.11	190.41	34
		LSS 35	8.36	11.22	19.58	523.86	12
		British Gypsum 40	8.36	25.07	33.43	1,022.18	6
Shepherd, Clarence Dock††	2 & 3	LSS 8	2.62	22.76	25.38	155.30	19
		LSS 35	2.27	11.22	13.49	360.90	8
		British Gypsum 40	2.27	25.07	27.34	835.94	4

* 8 cu. yd = 6.11 m^3; 35 cu. yd = 26.76 m^3; 40 cu. yd = 30.58 m^3
† Calculations for the three projects are based on the same skip size such that the charge per skip is the same.
** Capital cost = £6,500
†† Capital cost = £3,000

5.4 How best to exploit business case

Best practice in the use of the capture systems featured in the site trials in order to maximise the cost savings compared with the traditional capture methods currently employed on building sites is summarised below.

- There is a clear case for the use of a chipper. In all but one trial, implementation of a capture system incorporating a chipper resulted in cost savings. The advantage of a chipper is that it facilitates the use of a chute without the requirement to manually break up the waste plasterboard. This is repeated at skip level where the chipper waste reduces the proportion of air voids in a skip.
- It is advantageous to cover the plasterboard skip in order to reduce the potential of moisture being absorbed into the plasterboard. This was shown to increase the weight of the plasterboard in a receptacle by up to 10%.
- The chipper is best utilised on the floor where the waste is produced. The results from the Shepherd Clarence Dock trial show that operating the chipper on the ground floor adjacent to the skip takes longer and therefore costs more. Other methods to move the waste to the ground floor also have to be employed, adding significant extra costs.
- A chute that removes the requirement for manual handling of the waste both to and into the receptacles is significantly more efficient. Results from the Aylesbury and Clarence Dock trials demonstrate the benefit of this system. In addition, the success of the capture system at King's Place can be partially attributed to the use of a chute.
- The most efficient capture systems limit manual handling as far as possible. For example, a saving can be made if dry liners place plasterboard waste directly into bins rather than employing labourers to collect the waste later on. Further savings can be achieved if waste from these bins is placed directly into the chipper or skip rather than being stockpiled first.
- Sites need to ensure that skips are emptied (or removed and replaced) when full. This in turn ensures that the most efficient volume of waste is captured and therefore that best value for money is achieved.

6.0 The environmental business case

The chipper maximises the efficiency of transportation of plasterboard waste from the site. The expected reduction in emissions derived through its use result from the greater utilisation of the full load capacity of each truck on each journey. This is turn results from each waste receptacle containing a higher weight of waste and having a lower void space. In essence, an increase in the weight of plasterboard in each skip/bag reduces the total number of collections required during a project.

As such, the environmental analysis aims to quantify the carbon emissions savings associated with the optimisation of waste material transportation for recycling through the use of the chipper. A number of recycling and project scenarios were analysed:

- British Gypsum bag collections;
- 8 cu. yd skip collections;
- 16 cu. yd skip collections; and
- 40 cu. yd skip collections.

In each case, the carbon emissions[4] associated with the transport of waste plasterboard are compared (and savings calculated) for:

- wastage arising with un-chipped and chipped plasterboard;
- different waste containers (bags and different sized skips);
- varying recycling facility destinations; and
- use of different modes of transport (road and canal barge).

All these parameters are expected to have an impact on carbon emissions.

In order to present a range of different potential carbon savings, the project team added value to the analysis by utilising historical data (sourced through British Gypsum) from a number of Taylor Woodrow projects (Table 8) for which information was available on total weight of plasterboard waste.

Table 8 Taylor Woodrow projects used to demonstrate the environmental business case

Project	Type of project	Method of waste collection
Orsett Village development, Essex	Housing	British Gypsum bag
Grand Union Village (GUV), London	Mixed use	British Gypsum bag
Western Harbour, Edinburgh	Apartments	British Gypsum bag
Higher Broughton, Salford	Housing	Skip
Victoria Wharf, Cardiff	Apartments	Skip
Clarence Dock, Leeds	Mixed use – including offices	Skip
St Crispins Hospital redevelopment, Northampton	Healthcare	Skip
Lancaster Road, Hartlepool (new hospital)	Healthcare	Skip
King's Place, King's Cross, London	Commercial	Barge

The projects were selected to achieve a range of build types, geographical locations and total weights of plasterboard waste. The list represents the best mix available from the project data to which the team had access. Where skip collection was used, emissions estimates were calculated to represent of the use of 8, 16 and 40 cu. yd skips.

6.1 Methodology

The following methodology was used to assess the level of carbon dioxide (CO_2) emission savings achievable through use of the chipper to process plasterboard waste.

The various assumptions that had to be made to overcome a number of constraints to the analysis are presented in Appendix 3, including the issues raised by the lack of data on skips containing chipped waste.

[4] *As carbon dioxide emissions*

Data on the total weight of plasterboard generated on a range of Taylor Woodrow projects (Table 8) were collated.

To enable the 'best case' number of skips that could be filled to be determined, the project team determined the weight of chipped or un-chipped plasterboard waste that could be carried in different waste receptacles.

A trial was undertaken in a controlled environment[5] to assess the weights of British Gypsum bags containing either un-chipped or chipped plasterboard waste; these values are referred to subsequently as 'control' weights. Data from the St James Apartments, Cheltenham, on the weight of chipped and un-chipped 6 cu. yd skips were used as representative of skip weights as these were the most consistent data available in terms of numbers of skips in a relatively consistent environment. The control weights determined for British Gypsum bags and 6 cu. yd skips are given in Table 9. These were scaled up to arrive at values for larger skips.

Table 9 Control weights for un-chipped and chipped British Gypsum bags and 6 cu. yd skips

	Weight of British Gypsum bag (tonnes)	Weight of 6 cu. yd skip (tonnes)
Chipped	0.34	3.62
Un-chipped	0.245	3.08

These data were used to estimate (see Figure 21):

- number of un-chipped skips/bags that would be filled during each project; and
- number of chipped skips/bags that would be filled during each project.

These estimates were then used to calculate for each project:

- total number of journeys;
- length of each journey; and
- total number of miles travelled under chipped and un-chipped scenarios.

Finally, emissions data for heavy goods vehicles (HGVs) were used to calculate the total emissions under both scenarios and a final CO_2 saving derived. Table 10 shows the carbon dioxide (in gCO_2/mile) emitted from articulated lorries (used to transport British Gypsum bags) and rigid lorries (used to transport skips).

Table 10 Vehicle emissions per mile*

Vehicle type	Average speed (mph)	Emissions (g CO_2/mile)
Articulated lorry (Euro II Class)	40	2,511
Rigid lorry (Euro II Class)	40	1,076

* Taken from NETCEN emissions factor database, 2003 (see Appendix 3)

This approach was felt to allow the greatest use of existing data on plasterboard waste held by Taylor Woodrow; it applied historic data to control unit data (weight per skip/bag) on the weight of chipped and un-chipped skips/bags.

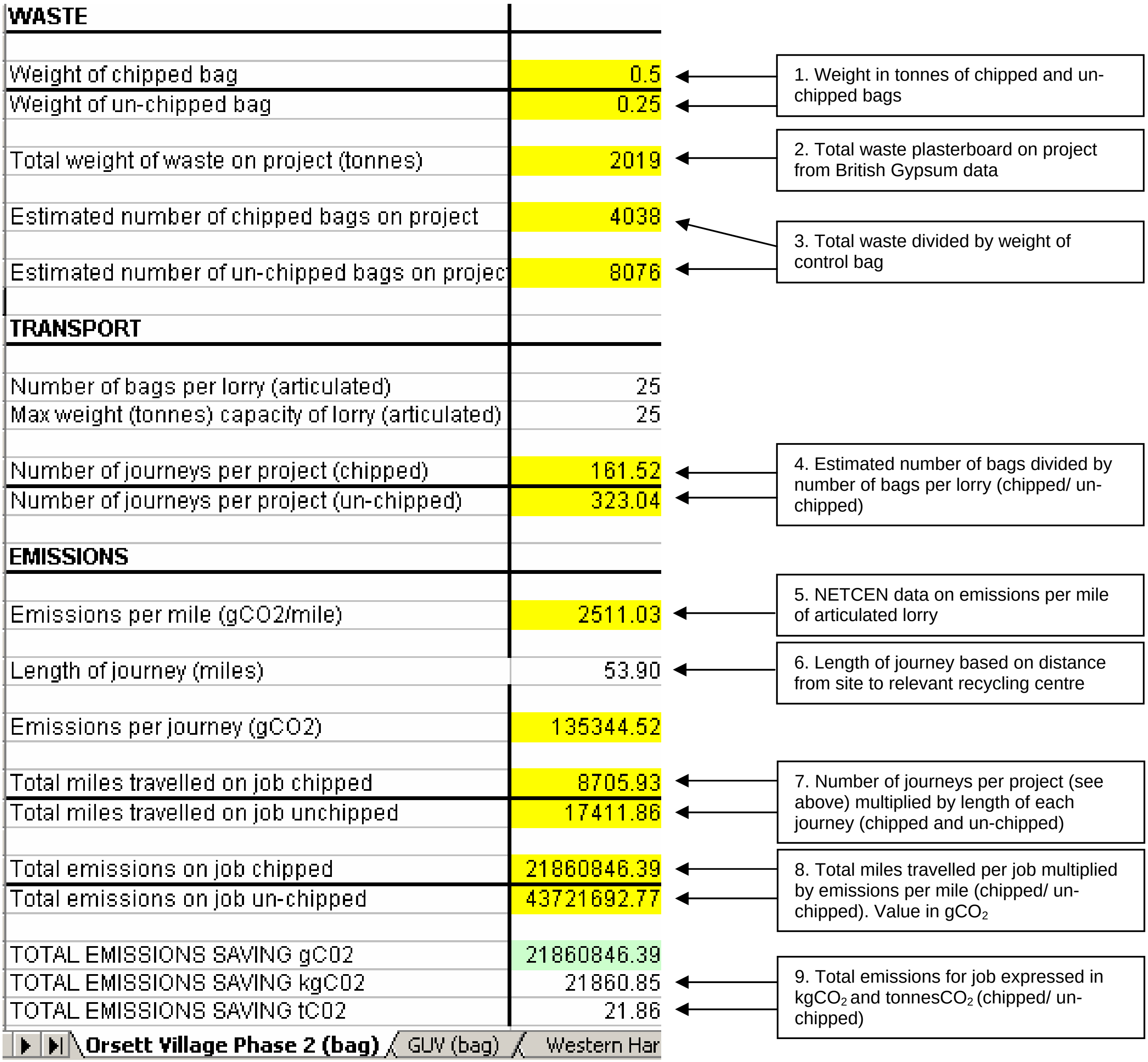
As stated above, a range of projects was selected in order to cover a number of sectors (e.g. housing, healthcare) and different scales of construction. It is anticipated that the number of un-chipped skips/bags required on each project will be significantly greater than the number of chipped skips/bags.

[5] *An environment where the material could be segregated and weighed immediately, accurately and without contamination by either other materials or adverse weather conditions.*

For each project, the distance travelled on each collection to the recycling facility was determined to enable the total distance travelled during the project under the un-chipped and chipped scenarios to be calculated. This was expressed as a total ‘un-chipped’ distance travelled and a total ‘chipped’ distance travelled.

Figure 21 contains an extract from the spreadsheet tool produced to calculate estimated carbon savings and illustrates the way in which carbon savings were derived. The spreadsheet shows that, for a project producing 2,019 tonnes of plasterboard waste (a large development), the difference of 250 kg between a chipped and an un-chipped bag will result in a saving of 21.86 tonnes of carbon dioxide (tCO_2) under the evaluation applied. For British Gypsum bag collections, only one leg of the journey is included in the calculation as it is assumed to be a ‘milk round’ collection where bags are collected from various sites.

Figure 21 Illustration of the emission saving calculation*†



* The values entered for the control weight of chipped and un-chipped bags are intended to illustrate how the tool works. They are not the actual weights used in the analysis.
† Yellow cells contain data that are either generated by the spreadsheet or are a consistent set of values. The green cell shows the calculated emissions.

The same approach was applied to projects using skips except that a two-way journey to and from the recycling centre was assumed. In addition, an evaluation was carried out that aimed to assess the emissions savings associated with the use of different size skips.

As an example of the results, Table 11 shows the different values obtained for the Higher Broughton project, which produced a total of 189 tonnes of plasterboard waste and was situated 104 miles from the recycling centre. The values were obtained using the spreadsheet shown in Appendix 4 following input of the control weights of chipped and un-chipped 8 cu. yd skips, and their scaling up to 16 cu. yd and 40 cu. yd skips.

The main aim of the comparison is to illustrate the most effective means of reducing carbon emissions on projects with respect to which receptacles to use. It is assumed that the weight of the skip will make it possible to transport.

It has also been assumed for this analysis that the carbon emissions resulting from the use of the chipper itself are negligible compared with the transport-related carbon emissions from HGV vehicles. A chipper running on a 18.2 amp, 110 volt supply for 2 hours (time taken to fill a skip) would have an extremely small energy consumption compared with transport via HGV over the project lifecycle.

Table 11 Example emissions savings from different skip sizes

Scenario (skip size, chipped / un-chipped)	Emissions (tonnes CO_2)
Total emissions	
8 cu. yd chipped	11.72
16 cu. yd chipped	5.86
40 cu. yd chipped	2.34
8 cu. yd un-chipped	13.78
16 cu. yd un-hipped	6.89
40 cu. yd un-chipped	2.76
Emissions savings: chipped versus un-chipped	
Total emissions – 8 cu. yd un-chipped	13.78
Total emissions – 40 cu. yd chipped	2.34
Emissions saving	**11.43**
Emissions savings: chipped – different skip size	
Total emissions – 8 cu. yd chipped	11.72
Total emissions – 40 cu. yd chipped	2.34
Emissions saving	**9.38**

6.2 Analysis of carbon savings

The analysis considered four key variables associated with carbon emissions:

- increase in skip/bag capacity through use of the plasterboard chipper;
- use of different size receptacles for waste plasterboard;
- distance of the site from a plasterboard recycling centre; and
- mode of transport used to transport the waste plasterboard.

In the case of the increased capacity of the skip/bag through chipping, the carbon savings result from the fewer journeys required to transport an equal weight of waste. For the use of different size receptacles (e.g. 40 cu. yd skip instead of 8 cu. yd skip), the savings also result from fewer journeys being required to transport an equal

weight of waste. This class of saving is related to increasing load capacity in order to reduce the total number of journeys required for a project.

The distance of the site from a recycling centre has an obvious effect on CO_2 emissions since the further away the recycling facility the greater the emissions per journey. Finally the mode of transport impacts on CO_2 emissions due to differences in the CO_2 emitted per mile by different vehicles (e.g. articulated versus rigid lorry).

Thus variables associated with CO_2 emissions are associated with:

- capacity (i.e. weight of plasterboard waste) achievable on each journey;
- distance of that journey; and
- carbon efficiency of the vehicle used to transport the waste.

6.2.1 Savings associated with using the chipper

Use of the chipper saves 27.9% of carbon emissions on projects using bags and 14.9% of carbon emissions on projects using skips (Table 12). The difference in the percentage of carbon saved is because the difference in weight of a chipped bag compared with an un-chipped bag (38%) is greater than this differential in skips (17%). The percentage of emissions saved as a result of chipping remains constant regardless of the size of the project or the distance travelled on each journey. Across all projects using bags, the percentage saving from using the chipper will be 27.9% even if the total weight of plasterboard waste and distance to recycling centres differ.

These data were derived in the case of bags from controlled filling and for skips from trials at the St James Apartments project in Cheltenham. However, other data indicate that the percentage improvement in weight and therefore resultant carbon emissions can vary significantly due to several factors as outlined below.

- **Different specifications**. Different specifications for different dry lined structures will result in varying mixes of boards being present in skips. In some cases, a greater total density of board in a skip may result in it being heavier than in other cases. This could increase the level of saving achievable through chipping.
- **Differences in water content**. Skips can vary greatly in weight depending on the amount of water that has either been absorbed by the plasterboard itself or is held within the skip. This can result in a change in weight, which could also increase the level of saving achievable through chipping.

Factors such as these could affect weights by up to 10–20%.

The difference in percentage savings between bags (27.9%) and skips (14.9%) may be because plasterboard offcuts broken down by hand are likely to create significant void spaces within bags due to their limited size compared with the size of the off-cut. Similar sized offcuts in skips are likely to pack down more effectively, reducing void space per unit of weight compared with bags. Chipping may therefore reduce the void spaces in bags more significantly than in skips; when chipped, a greater increase in weight is observed in bags than skips.

It is possible that any combination of the factors above may have had an impact on the data used in this project as data for skips were derived from a live project environment.

Table 12 indicates the total CO_2 savings associated with the use of the chipper for three projects using bags and five projects using skips (8 cu. yd). As shown in the Summary Sheet in Appendix 4, the carbon savings associated with use of the chipper range from 12.47 tCO_2 (Orsett Village, bags) to 0.04 tCO_2 (St Crispins, 40 cu. yd skips). This range results predominantly from differences in the total weight of plasterboard waste requiring transport, but also the distance of the site from the recycling centre.

Table 12 Total emissions, total savings and savings tCO_2/t waste (chipped) for eight Taylor Woodrow projects

Project	Removal method	Total waste (tonnes)	Unit distance per journey (miles)	Total tCO_2		Total saving (tCO_2)	tCO_2 per tonne of waste (chipped)	Saving (%)
				Un-chipped	Chipped			
Orsett Village	Bag	2,019	54	44.61	32.15	12.47	0.016	27.9
GUV	Bag	383	85	13.27	9.56	3.71	0.025	27.9
Western Harbour	Bag	171	297	20.81	15.00	5.82	0.088	27.9
Higher Broughton	8 cu. yd skip	189	209	13.78	11.72	2.05	0.062	14.9
Victoria Wharf	8 cu. yd skip	217	336	25.49	21.69	3.80	0.050	14.9
Clarence Dock	8 cu. yd skip	58	161	3.27	2.78	0.49	0.048	14.9
St Crispins	8 cu. yd skip	34	108	1.28	1.09	0.19	0.032	14.9
Lancaster Road	8 cu. yd skip	22	308	2.37	2.02	0.35	0.092	14.9

6.2.2 Projects using bags

The large-scale residential development at Orsett Village created 2,019 tonnes of plasterboard waste, which were transported to a recycling facility approximately 54 miles away. In this case, the analysis indicates that the increased capacity achieved through chipping plasterboard into bags would have resulted in a total emissions of 32.15 tCO_2 compared with 44.61 t CO2 for un-chipped plasterboard, i.e. a saving of 12.47 tCO_2 (see Appendix 4 Summary Sheet).

At the other end of the scale, the much smaller Western Harbour development in Edinburgh generated only 171 tonnes of plasterboard waste, which were transported off site in bags. Had this waste been chipped into bags, this would have resulted in total emissions of 15 tCO_2 and a saving of 5.82 tCO_2 compared with not chipping waste. However, each lorry load of bags was transported nearly 300 miles to a recycling facility and therefore emissions levels were high relative to the total tonnage of waste.

As a result the tCO_2 emitted per tonne of plasterboard waste recycled for Western Harbour is 0.088 compared with 0.016 for Orsett Village (table 12). This is the direct result of the additional 242 miles travelled on each load for the Western Harbour project compared with the Orsett Village project. In both cases, the percentage of CO_2 saving from using the chipper is 27.9%.

6.2.3 Projects using skips

For the projects using 8 cu. yd skips, the range of total savings achievable again results from differences in the total amount of waste to be recycled in each project and the distance of each site from a recycling centre. But in each case, the percentage level of saving through using a chipper remains at 14.9% (Table 12). In all cases, the distances from the recycling centre were significant compared with those of some of the projects using bags. This is likely to be the reason why the tCO_2 emitted per tonne of plasterboard waste recycled is high for these projects compared with both Orsett Village and GUV (Table 12).

The two smallest scale projects, St Crispins and Lancaster Road, produce some interesting results. Despite a larger tonnage of waste at St Crispins, the total emissions associated with removing chipped plasterboard waste are lower than at the Lancaster Road project. This is the result of the significant extra distance travelled per journey at the Lancaster Road Health Centre, which more than offsets the five extra journeys required at St Crispins. This increased emissions total means that the total saving (through using chipped compared with un-chipped skips) is almost twice as great for the Lancaster Road project.

Table 13 shows the savings achievable from the five skip projects in Table 12 for 16 and 40 cu. yd skips (see also Appendix 4). This table demonstrates that the savings achievable through a switch from un-chipped to chipped

skips decrease as the receptacle increases in size. This is because more journeys are required with smaller skips and therefore there is a greater weight of emissions to save against by chipping. While the saving from chipping remains at 14.9%, this saving is greater where more emissions are released. This is reflected in the fact that the tCO_2 emitted per tonne of plasterboard waste recycled drops as larger skips are used and fewer journeys are undertaken. This observation is expanded on in section 6.2.4.

Table 13 Comparison of carbon savings achievable from chipping waste plasterboard into three skip sizes

Project	Total saving (tCO_2)		
	8 cu. yd	16 cu. yd	40 cu. yd
Higher Broughton	2.05	1.03	0.41
Victoria Wharf	3.80	1.90	0.76
Clarence Dock	0.49	0.24	0.10
St Crispins	0.19	0.10	0.04
Lancaster Road	0.35	0.18	0.07

6.2.4 Savings associated with using different size receptacles for waste

The analysis above might at first glance suggest that plasterboard bags are the most effective receptacle for transferring waste to recycling centres since the percentage saving associated with a switch to chipped plasterboard (27.9%) is nearly twice that for skips (14.9%).

However, this difference is only an indication of the effectiveness of chipping to increase capacity – and therefore emissions – in bags and skips respectively. It does not have any bearing on which receptacle type is most efficient, in general, at utilising full lorry capacity and therefore reducing emissions. Table 14 shows a comparison between the emissions that would have been derived from the Orsett Village project through the use of chipped bags, 8 cu. yd skips, 16 cu. yd skips and 40 cu. yd skips.

Table 14 Comparison of emissions from the Orsett Village project through the use of different receptacles*

Receptacle	Number of journeys	Total carbon emissions from chipping (tCO_2)	tCO_2 / tonne of plasterboard waste
Bag	238	32.15	0.0159
8 cu. yd skip	558	32.35	0.016
16 cu. yd skip	279	16.18	0.008
40 cu. yd skip	112	6.47	0.003

* Vehicle emissions per mile for skips are 1,076 gCO_2/mile (rigid lorry) and 2,511 gCO_2/mile (articulated lorry) for bags. Total waste generated was 2,019 tonnes and the distance of each journey was 54 miles.

The data indicate that the lowest level of carbon emissions would have been achieved by transferring waste plasterboard to a recycling centre using large 40 cu. yd skips. The next most effective container is the 16 cu. yd skip. Finally, bags and 8 cu. yd skips produce the greatest volumes of carbon dioxide (the difference in tCO_2 per tonne of waste between them is negligible).

In the case of 8 cu. yd skips, significantly more journeys are required (558) compared with bags (238). In this case, the additional 320 journeys required for disposal by skip are almost exactly offset by the rigid skip lorry carrying the skips emitting approximately 1.5 times less CO_2 per mile than the articulated lorry carrying the bags. As such, both the total emissions and the tCO_2 emitted per tonne of plasterboard waste recycled are nearly identical for 8 cu. yd skips and bags.

But while more journeys are required to transport the 2,019 tonnes of waste via 16 cu. yd skips (279) than by bag (238), the difference is small enough to be significantly offset by the lower emissions of the rigid lorry compared with the large articulated lorry. As a result, the total emissions and the tCO_2 emitted per tonne of

plasterboard waste recycled are significantly lower for 16 cu. yd skips compared with bags. In fact, the total carbon emissions for 16 cu. yd skips are almost half those for bags.

However, 40 cu. yd skips require fewer journeys and are transported on the lower emission rigid lorry and, as such, prove to be the most carbon efficient receptacle in terms of emissions.

To illustrate the maximum saving possible, the carbon saving achieved by making a switch from not chipping into an 8 cu. yd skip to chipping into a 40 cu. yd skip was calculated for the Orsett Village project (Table 15).

Table 15 Maximum possible savings from Orsett Village project

Plasterboard capture system	**Total project emissions (tCO_2)**
Un-chipped 8 cu. yd skips	38.02
Chipped 40 cu. yd skips	6.47
Saving	**31.55**

6.2.5 Savings associated with using closer recycling facilities

At Clarence Dock two sites are in operation within the same area. However, the site operated by Shepherd Construction uses a recycling facility approximately 2.6 miles away while the other site under Taylor Woodrow's management uses a British Gypsum facility that is 160 miles away.

The total waste data from the TWC site can be used to compare the emissions saving that would be derived from using the closer facility. Table 16 illustrates the total emissions (tCO_2) from the project as a result of using the two different facilities. Total emissions obviously vary depending on which size skip is used since 40 cu. yd skips are more efficient on the basis of tCO_2/tonne waste.

Table 16 shows that the level of carbon savings achievable through using a much closer recycling facility is significant, in particular for 8 and 16 cu. yd skips. This saving is approximately 97% in each case, indicating the critical importance of distance travelled per journey in reducing emissions.

Table 16 Carbon savings achievable through use of closer recycling facilities to Clarence Dock*

	8 cu. yd skip	**16 cu. yd skip**	**40 cu. yd skip**
Total emissions (tCO_2) – 2.6 mile facility	0.07	0.04	0.01
Total emissions (tCO_2) – 160 mile facility	2.78	1.39	0.56
Saving (tCO_2)	**2.71**	**1.36**	**0.54**

* Total waste on project = 58.25 tonnes

6.2.6 Savings associated with using alternative modes of transport

At King's Place, the Sir Robert McAlpine project has been disposing of waste plasterboard by barge a short distance to a recycling facility accessible directly from Regent's Canal. This analysis attempted to determine the level of carbon savings achievable through the use of canal rather than road. However, data for CO_2 emissions from barges are not commonly available and it was necessary to use a figure quoted in a European Commission study[6] in order to make ballpark estimates of the savings potential from using canal instead of road. This study stated that one-sixth of the energy is used – per unit transported – by barges compared with lorries.

At King's Place, the recycling facility is only 6.4 miles from the site by road. Had the project used 8 cu. yd skips in which to chip into and transported this material via road, then total emissions would have amounted to 0.108 tCO_2. However, the use of barge means that total emissions may have been as low as 0.01 tCO_2.

[6] *Cited in a case study by Sea and Water (www.seaandwater.org/downloads/canarywharf.pdf)*

To illustrate the potential of using a canal barge as a means of transporting plasterboard waste for recycling, Table 17 shows the approximate CO_2 savings that could be achieved on each of the projects in the analysis by using a barge. The table uses bags (first three projects) and 8 cu. yd chipped skips (last five projects) as a means of comparison.

Table 17 Approximate savings achievable on each project as a result of replacing road transport with canal barge

Project	Removal method	Total waste (tonnes)	Total tCO_2 chipped (road)	Total tCO_2 chipped (barge)	Saving tCO_2
Orsett Village	Bag	2,019	32.15	5.36	26.79
GUV	Bag	383	9.56	1.59	7.97
Western Harbour	Bag	171	15.00	2.50	12.50
Higher Broughton	8 cu. yd skip	189	11.72	1.95	9.77
Victoria Wharf	8 cu. yd skip	217	21.69	3.62	18.07
Clarence Dock	8 cu. yd skip	58	2.78	0.46	2.32
St Crispins	8 cu. yd skip	34	1.09	0.18	0.91
Lancaster Road	8 cu. yd skip	22	2.02	0.37	1.65

6.3 How best to exploit the environmental case

The key findings of the analysis are summarised below to enable the environmental case to be exploited most effectively in pursuit of reducing the carbon emissions associated with the transport of plasterboard waste for recycling.

The data suggest that all four of the variables identified in section 6.2 may have an impact on carbon emissions. These variables include:

- increase in skip/bag capacity through use of the plasterboard chipper;
- use of different size receptacles for waste plasterboard;
- distance of the site from a plasterboard recycling centre; and
- mode of transport used to transport the plasterboard.

In an ideal scenario, a project would have access (possibly via canal) to a recycling facility that is local to the site and would transport plasterboard in large containers such as 40 cu. yd skips. This would reduce the individual journey distance and the number of journeys during the project. Both these factors will have a significant impact on carbon emissions. In addition, the evidence suggests that a carbon saving of 14–28% can be achieved through chipping plasterboard into waste containers.

Obviously this scenario is not possible in all circumstances as the site footprint often inhibits the use of larger 40 cu. yd skips and, on many sites (particularly remote ones), recycling facilities may be some distance from the site. As such, it is important to try to optimise the capacity of the project to reduce emissions by considering which of the variables are viable in the project's context. For example, projects sited a large distance from a recycling facility should aim to offset carbon emissions by using larger waste containers.

The general principles that should be considered in reducing emissions on projects are discussed below.

6.3.1 Use of the chipper

Use of the chipper results in carbon savings by reducing the total number of collections required during a project. This saving can be as much as 12 tonnes of CO_2 on large-scale residential developments.

The results also suggest that the level of carbon savings derived through chipping is greater in bags (27.9%) than in skips (14.9%). However, this information should be used with caution as the data suggest that bags are not generally the best means of reducing carbon emissions on a project.

6.3.2 Use of 40 cu. yd skips

The use of 40 cu. yd skips appears to be the most effective way to achieve maximum capacity in terms of waste transfer by also reducing the total number of collections required during a project. The analysis was not able to account for the increase in emissions per mile that results from having a heavier load on the back of a lorry, but

this increase is not anticipated to offset the considerable reduction in the number of journeys achieved through using larger skips.

If it is not feasible for financial or logistical reasons (e.g. availability of space) to use a large skip such as a 40 cu. yd skip, then a 16 cu. yd skip should be used. Use of bags and 8 cu. yd skips may result in high emissions levels, particularly when the recycling facility is a long way from the site. If this is the case, use of a 40 cu. yd skip should be a priority in order to offset against greater journey distances.

6.3.3 Reduction of journey distance to recycling facility

This analysis has suggested that the transport distance to the recycling facility is the most significant contributor to carbon emissions. While larger receptacles can reduce the number of journeys on a project, a significant mass of CO_2 will be released into the atmosphere if each journey is 100 miles or more. But if a recycling centre can be located close to the site, then this may offset the use of smaller skips (e.g. 8 cu. yd skips).

6.3.4 Use of alternative modes of transport

While this analysis has stopped short of profiling in detail the carbon emissions that can be saved as a result of using barge rather than road, it has indicated the potential for the use of barges. On longer haul routes, this would be particularly marked as the number of journeys can be reduced to one or two as barges can carry up to 80 tonnes of plasterboard waste compared with approximately 25 tonnes on articulated lorries.

7.0 Implementing best practice on site

Many lessons can be learnt from the project on the implementation of plasterboard capture systems on construction sites. This section seeks to document and illustrate (where appropriate) these lessons by first establishing the case for investment (drawing together the business and environmental cases from previous sections), illustrating a best practice scenario and then detailing some step-by-step points on implementing a capture system and how to maintain buy-in for these systems.

7.1 Background – the case for best practice

It is estimated that, on average, 12% of all plasterboard brought to site is wasted.[7] Throughout this project, however, wastage rates as high as 25% were witnessed. While this is a significant cost in terms of raw material and waste disposal costs, the economic analysis in section 5 highlights just how significant this volume of waste is in terms of labour costs.

Obviously best practice is not to waste the plasterboard in the first place and much work is being done in the minimisation of plasterboard waste. However, this study is concerned with the management of those wastes that are not eliminated.

From a purely economic perspective, the true cost of plasterboard waste includes:
A: cost of disposal/recycling;
B: labour costs of handling the waste;
C: equipment costs of handling the waste (i.e. bins/chutes); and
D: cost of the material.

Further factors that may be difficult to quantify add additional costs to the management of plasterboard waste. These include:
E: internal transport costs (i.e. forklift time);
F: storage costs; and
G: lost time costs (i.e. through hoist being tied up moving waste).

Section 5 highlights some of the savings that can be achieved through the use of an efficient plasterboard capture system. These savings focus on points A–C above.

- Waste costs at the TWC Clarence Dock example were 45% less with the chipped system compared with the manual one (Table 5).

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[7] *Market Transformation Programme. September 2007.* Plasterboard – industry, product and market overview*. BNPB1. Version 1.3 (www.mtprog.com/ApprovedBriefingNotes/PDF/MTP_BNPB1_2007October9.pdf)*

- At the Aylesbury example, labour costs were reduced by 51% through the use of a chipper and a chute (over manual handling).
- The King's Place example highlighted the benefits of early implementation of an efficient plasterboard capture system in delivering efficient labour costs for a large project.

From an environmental perspective, the critical element highlighted in section 6 is the mass (or volume) of the plasterboard waste. By reducing the number of vehicle movements to a minimum through maximising the quantity of waste per journey, it is possible to lessen the environmental impact of moving the plasterboard waste.

The data suggest that all four of the variables below may have an impact on carbon emissions:

- increase in skip/bag capacity through use of the plasterboard chipper;
- use of different size receptacles for waste plasterboard;
- distance of the site from a plasterboard recycling centre; and
- mode of transport used to transport the plasterboard waste.

An ideal scenario would address all four variables through the use of a chipper, the use of a 40 cu. yd skip (or larger), a reduced journey distance to the recycling centre and an alternative means of transport (e.g. a canal barge).

7.2 The best practice scenario

Successful application of a plasterboard capture system depends on a number of factors common to all construction sites. Thorough consideration of all relevant factors is essential to ascertain the feasibility and ease of application for a particular methodology.

A number of different capture systems are currently available for plasterboard waste from construction sites:

- British Gypsum's bag system;
- segregated skip system;
- part segregated skip system;
- mixed skip system;
- mosquito fleets (small trucks).

However, there is little guidance on where (and how) these methodologies can best be applied. This lack of guidance causes problems for those sites where traditional capture methodologies are unsuited to site conditions and can discourage sites from adopting them. Typical barriers/enablers are presented in Table 18.

- The complexity of operations on a construction site often mean that trades with the potential to reuse offcuts from another trade are contractually, habitually or technically restrained from doing so. For example:
  - Dry liners rarely reuse offcuts due to the need for a straight edge.
  - Variations are carried out with an entirely new set of materials due to a change in contractor.
  - There often has to be a substantial case for waste minimisation before methodologies can be put into place.
  - Waste board is required to be cleared for health and safety reasons.
- Technical barriers concerning the recycling process are often a problem on construction sites due to the difficulties associated with keeping materials free from contamination. With materials as sensitive as gypsum, it requires very little moisture for the plasterboard recyclers to reject the material as unusable.
- On larger construction sites, plasterboard is often sourced from more than one supplier, especially on phased developments. Since most plasterboard manufacturers generally run recycling operations exclusively for their own materials, this means that more than one capture methodology may be required on a single site. If the waste is not sent back to the plasterboard manufacturer but is destined for alternative end uses, the capture methodology may be less critical.

Table 18 Critical factors in the adoption of a plasterboard capture system on construction sites

Factor	Negative aspects	Positive aspects
Space	Small site footprint: A limited site footprint with little room to segregate plasterboard waste. Poor storage facilities.	Large site footprint: A large site with sufficient room to segregate plasterboard waste. Good storage facilities.
Time	Short lead-in: Limited time to setup a complicated capture system.	Long lead-in: Enough time to set up alternative means of disposal.
	Rapid rate of construction: No time/labour to segregate the plasterboard waste.	Standard rate of construction: Labour available on site to police segregation.
Client requirements	Sub-contract documentation/proactive client/degree of influence allocated to lead contractor: Client/manufacturer/sub-contractor buy-in.	
Location	Rural Limited alternative means of disposal available locally. Distance to plasterboard recycling centre (applies to all).	Urban Local alternatives to landfill available.
Duration	Short (<15 weeks) A short and small-scale project or strict/heavy liquidated and actuated damages (LADs) in force.	Long (>52 weeks) A project duration long enough to warrant time/labour investment in segregation.
Size of the waste stream	Small (infrastructure projects)	Large (high rise residential)
Waste disposal regulations	The 10% rule enforced by the Environment Agency[8] encourages the use of general waste skips for plasterboard disposal where no local plasterboard recycling scheme is available.	

7.2.1 Cost perceptions

The perception that recycling plasterboard is prohibitively expensive compared with sending it to landfill under the 10% rule is a consistent barrier to the development of the recycled market for plasterboard. If sites automatically contract waste management companies to dispose of plasterboard waste to landfill rather than investigating possible plasterboard recycling schemes locally, they may be missing a more sustainable and competitive option and, in turn, stunting the development of a recycling market for plasterboard.

Throughout this project it was evident that local waste management options for plasterboard recycling can be extremely competitive. Increasingly companies appear to be taking advantage of a more established market for plasterboard waste and are directing wastes to end uses such as soil conditioners (Leeds) or soil stabilisers (London). Where such a local facility exists, it is often more economical than landfill. This is illustrated in Table 19, which gives the costs associated with the disposal/recycling of a 40 cu. yd (or equivalent) skip of plasterboard waste from Clarence Dock, Leeds.

Table 19 Costs of different waste management options at Clarence Dock*

[8] *Environment Agency. July 2005.* Gypsum wastes and high sulphate bearing wastes, *GEHO0705BJIX-E-E (www.environment-agency.gov.uk/commondata/acrobat/gypsum3_1122535.pdf)*

Option	Cost per 40 cu. yd skip†
Landfill (mono cell – Scunthorpe)	£1,240
Local waste management company (soil conditioner)	£235
Plasterboard recycling system	£600

* For either site.

† Skip assumed to contain 10 tonnes of waste plasterboard

7.2.2 Suggested measures

To take advantage of the potential benefits of best practice, careful thought needs to be given to the plasterboard capture systems in use on site. Proven measures considered to offer the most efficient means of plasterboard capture are listed below under the stage to which they apply. Note that not all these measures will apply to all construction sites/projects.

Point of waste

- Place a wheelie bin in each room currently being boarded and encourage the fixers to place the waste directly in the bins. At the TWC Clarence Dock site, this activity saved an average of £6.98/m^3 or 18% of the total capture system costs (after chipping).
- Encourage labourers to stockpile the plasterboard waste in bins rather than directly on the floor. This reduces the potential for double-handling the waste and possible contamination. It also reduces the risk of accidents resulting from tripping over the waste.

Chipping

- Locate a chipper as close to the waste production as possible, ideally on the same floor.
- A chipper pays for itself (using 40 cu. yd skips) when a minimum of 56 m^3 of plasterboard waste is created on a project. However, this payback relies upon sufficient quantities being created at one location such as a floor or a unit.
- If <56 m^3 of waste is being created at one point, the labour costs associated with moving the waste to the chipper are likely to exceed the value gained from chipping the waste.

Manual handling

- Try to minimise the amount of manual handling in the capture system. A large proportion of manual handling (and therefore cost) can be eliminated through:
  - the use of wheelie bins and chutes; and
  - the location of skips adjacent to the building footprint

Receptacle

- The best receptacle from an economic and environmental perspective is a large one. From an economic perspective, larger receptacles are cheaper (per m^3) due to economies of scale on behalf of the waste management company. From an environmental perspective, the reduced number of collections required for larger receptacles translates into reduced carbon dioxide emissions from transportation.
- Covering skips (particularly if using chipped material) is advantageous if paying for skips by weight. It was shown during the trials that wet plasterboard can increase skip weights by over 10%.
- Try to locate the receptacle as close to the building footprint as possible, particularly if using chutes, as this reduces the labour costs associated with moving the waste into the receptacle.

Waste management

- Undertake a thorough examination of all local waste management options before selecting your waste management contractor for plasterboard. The cost of recycling plasterboard can vary significantly depending on local end use options.

However, all these suggestions are best attempted in consultation with all the stakeholders in the plasterboard capture system. The next section provides some guidance on how to undertake this process.

7.3 Planning a plasterboard capture system

For capture systems to function effectively, it is important to ensure stakeholder buy-in early on in the project. Early implementation is preferential to trying to implement a capture system mid-way through a programme.

By planning the operation of a capture system upfront in the programme and involving all the relevant stakeholders, it is not necessary to stimulate change in the site practices later on. It also allows for the planning and erection of chutes and other auxiliary items.

The stakeholders involved in a plasterboard capture system are:

- main contractor;
- dry lining sub-contractor; and
- waste management company/plasterboard recycling company.

If a project is dealing directly with a plasterboard manufacturer or indirectly through a distributor, it is advantageous to also engage with these parties.

To stimulate change on site, there needs to be a strong, proven business case in order to ensure buy-in. Different levels of management require different levels of business case (Table 20), both in terms of incentives and also in terms of methodology.

Table 20 Requirements to promote buy-in to the proposed plasterboard capture system

Management level	Level of business case
Site management	High level figures. Proven case studies. Demonstration of machine.
Site foreman	Involve in establishing methodology on site. Ensure buy-in before approaching labourers.
Site labourers	Use foreman to dictate change. Demonstrate usage on site.

As noted above, there is often a need to highlight the misconceptions regarding existing systems. This could include:

- ensuring that the true cost of waste is understood;
- highlighting inefficiencies with current methods of plasterboard capture; and
- ensuring clear and delegated responsibilities.

Once all parties are engaged, it is preferable to hold a meeting with everyone present in order to work through a logical progression of the dry lining process on site. This meeting should seek to:

- identify any inefficiency with the proposed method of works – materials lying around on site for a time, double-handling of the waste, excess waste budgeted for in the take- off (If it is 10%, why is it 10%?); and
- work together to propose more sustainable solutions.

7.3.1 Roles and responsibilities during planning

Main contractor

- Bring together the stakeholders in the dry lining package at a meeting held early on in the project (well before the dry lining package is due to start).
- Present a logical agenda taking each step through the dry lining package (Table 21).

Table 21 Management of plasterboard around site

Step	Considerations
Delivery to site	■ Packaging ■ Pallets ■ Division of responsibility
Storage on site	■ Minimal storage on site ■ Undercover and well-protected
Movement around site	■ Protection from damage ■ Avoidance of double handling ■ Consideration of specialist equipment
Waste management	■ Waste material movements on site – devise the most efficient method for the site. Include chutes, bins, etc. ■ Division of responsibilities ■ Training ■ What percentage waste is allowed for in takeoff? Why? What can be done to help reduce this? ■ Most efficient means of disposal – skip size, use of chipper, etc.

- Build the capture system into the project programme (i.e. chutes, etc.) and ensure everybody signs up to it.
- Highlight the true cost of waste including labour costs, material costs and damage in addition to the waste disposal costs.
- Consider factors such as the site power supply if using the chipper on site.

Dry lining contractor

- Bring your takeoffs and your planned method of works to the meeting (above).
- Contribute your knowledge about where wastage occurs and suggest your preferred method of managing the waste.
- Review your takeoffs and planned method of works in light of the discussions at the meeting.

Waste management company

- Bring details of skip sizes/costs and local recycling options to the meeting.
- Identify the most efficient option for the site taking account of the economic and environmental benefits identified in this report.

7.4 Implementing a plasterboard capture system

As mentioned previously, it is preferable to implement one capture system on site (although iterations of this capture system are to be expected). Any substantial changes in practice mid-way through a project are likely to be met with resistance.

When implementing a plasterboard capture system, it is useful to bear in mind the best practice described in this report. A division of responsibilities for ensuring this best practice is suggested below.

7.4.1 *Roles and responsibilities during implementation*

Main contractor

- If working on a high rise residential project, try to incorporate a clearly labelled dedicated chute for plasterboard waste with access points at each likely source floor. It may be necessary to police this to stop other trades placing materials down the chute. Installing a chute avoids the need for manual handing of the waste from the source floor to the ground floor.
- Try to ensure that skips are removed from site only when full. Several examples within this study pointed to 40 cu. yd skips being removed with as little as two tonnes of waste for the purpose of creating space on site at critical construction points. A 40 cu. yd skip fully loaded with chipped plasterboard (dry) should weigh 12–15 tonnes.

Dry lining contractor

- Ensure fixers place plasterboard waste directly into the bins so that double-handling can be avoided and Stage 1 (illustrated in the economic analysis) can be eliminated.
- Operate a chipper on the source floor to ensure that material is transferred to the ground floor receptacle in the most efficient manner. It was demonstrated during the trials that chipping on the ground floor dramatically reduces the savings potential offered by the chipper. This is due to the double-handling of the material.
- Ensure that labourers are trained and fully understand the most efficient means of plasterboard capture. This includes coaching operatives in how they collect the waste, the equipment they use and how they plan their workflow. Arrange a suitable toolbox talk covering these aspects. This will help to achieve significant efficiency gains over and above the simple volume improvements achieved in the waste containers and help towards achieving buy-in.

Waste management company

- Provide updates on the quantities of waste being collected from site. This will allow performance to be measured and any areas of concern addressed early on.

7.5 Maintaining buy-in throughout the project

Once a capture system is up and running, it should continue relatively unaided on the part of the site management. In some cases and where sites have to modify the capture system to suit site/programme characteristics, however, it may be necessary to reinforce the system through a process of review and reporting of progress. A suggested approach should a change of practice occur is given below.

7.5.1 *Roles and responsibilities should a change of practice occur*

Main contractor

- Reconvene the stakeholders in another meeting for the purposes of reviewing the information held to date. Use this review to identify:
  - savings to date (and stimulate buy-in for the next phase of the capture system); and
  - any inefficiency in the current system.

Dry lining contractor

- Feedback any lessons learned from the first phase of the capture system.
- Make suggestions based on this knowledge for the second phase.

Waste management contractor

- Highlight the savings made as a result of the good practice on site.
- Make suggestions if there are areas of inefficiency.

7.6 Review

When the construction project is complete, take time to review the performance of the plasterboard capture system. Monitoring and recording results, giving praise and positive feedback all help toward achieving buy-in on future projects. This also completes the loop towards continuous improvement.

8.0 Conclusions

The project has developed a clear business case (economic and environmental) for the effective planning of plasterboard capture systems (including the use of chippers if appropriate) on construction sites.

High rise residential sites, in particular, have significant potential to produce benefits (both economic and environmental) through effective planning. Although savings can also be achieved on low rise residential and housing developments, there are a number of limitations to achieving their full potential (see section 2).

8.1 Economic benefits

Significant cost savings through a reduction in labour costs and waste disposal costs (per m^3) are possible with an effective plasterboard capture system implemented in consideration of site conditions.

The trials described in this report deliberately focused on the perceived quick wins exhibited on high rise residential developments. In this manner it was hoped the innovative approach of these trials would stand the best chance of positive gain.

It was shown that existing capture systems (without the use of a chipper and with, often, little planning) have significant potential for improvement. It was also shown that savings of up to 47% (see Table 5) on total costs of plasterboard capture were achievable by focussing on reducing manual handling and increasing the quantity of material in the skips.

Gains on low rise sites are possible with effective consideration of the site conditions, but they are not expected to be in the order of those experienced on high rise sites.

Waste generation varies between high rise and low rise sites – a team of fitters only works on one block of apartments at any one time whereas six different houses may be fitted simultaneously. But although the movement of waste is labour-intensive, the number of sources and the relatively low quantity of board (in any one place) make it difficult to apply a consistent plasterboard capture methodology.

8.2 Environmental benefits

The economic savings illustrated in section 5 also translate into environmental savings (in terms of tonnes of carbon dioxide emissions saved) as it becomes possible to move more material per journey and thereby reduce the number of journeys required by a site.

All four of the variables below may have an impact on carbon emissions. These variables include:

- increase in skip/bag capacity through use of the waste plasterboard chipper;
- use of different size receptacles for waste plasterboard;
- distance of the site from a plasterboard recycling centre; and
- mode of transport used to transport the plasterboard.

An ideal scenario would address all four of these variables through the use of a chipper, the use of a 40 cu. yd skip (or larger), a reduced journey distance to the recycling centre and an alternative means of transport (such as a canal barge).

These savings can be achieved by:

- placing the largest receptacle possible on a site (a barge was shown to operate well if such a facility exists); and
- chipping the waste plasterboard directly into the receptacles in order to reduce air voids.

8.3 Plasterboard chipper

The trials of the plasterboard chipper showed it worked well in improving the business and environmental cases for a capture system. In all but one trial, the implementation of a capture system incorporating a chipper resulted

in cost savings. This highlighted both the potential of the plasterboard chipper and the need to plan its application carefully. This project also facilitated some valuable development work on the Starke Arvid chipper, which is now being marketed in the UK and elsewhere in the world.

8.4 Best practice guidance

Throughout the project many lessons were learned through the implementation of plasterboard capture systems at the trial sites. This information is reported in the form of guidance (see section 7) and provides a framework within which to target continual improvement in this area.

This guidance stresses the need to plan a plasterboard capture system and gives examples of what could be considered best practice (in light of the findings from this study). It also highlights the roles and responsibilities of the stakeholders (main contractor, dry lining sub-contractor, waste management company) at each stage in the process.

8.5 Limitations of the study and further work

As explained in section 1, the following areas were not investigated in this project:

- measures to reduce the generation of plasterboard waste (i.e. waste minimisation);
- infrastructure for plasterboard waste recovery/recycling; and
- comparisons between waste management options (though some are made in section 7.2.1 to illustrate cost perceptions about plasterboard recovery).

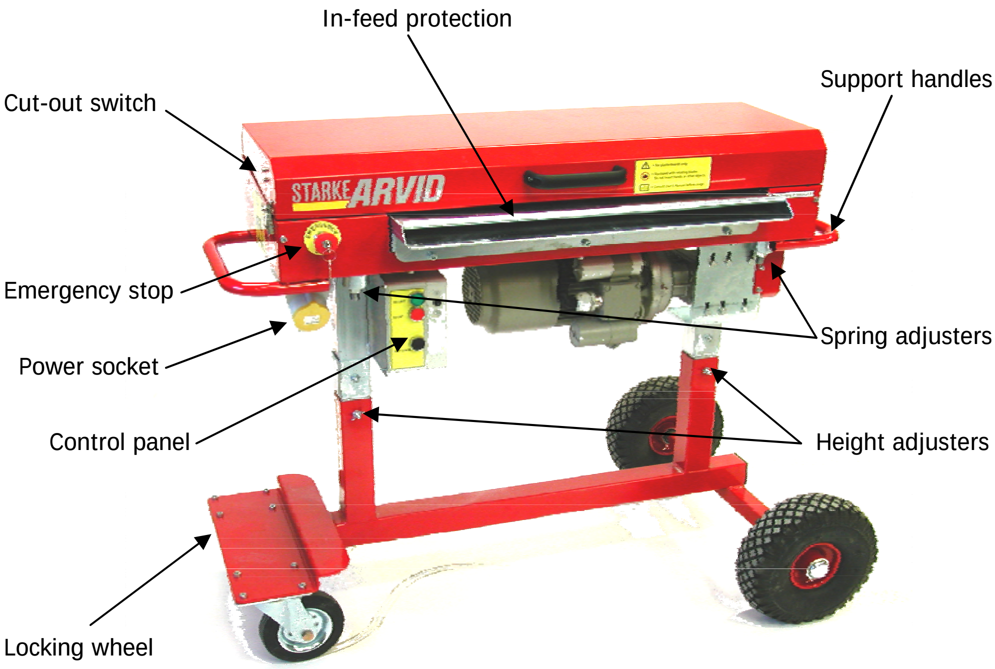
These limitations were deliberate so that the study could focus on those aspects directly relevant to the plasterboard capture system on site. However, it is implicit that these factors do have a bearing on improving waste management practices within the dry lining sector. In particular, considerable benefit could be achieved by targeting future work on the minimisation of plasterboard waste, as figures from the analysis of the site trials show there is much work still to do in this area.

A further limitation relevant to plasterboard capture systems was the omission of low rise sites from the analysis. Although there was a good reason for omitting these sites from this study, there is still a need to develop solutions for these types of site. Initial indications suggest that work should look first at waste minimisation and then address labour and waste disposal costs, with environmental aspects forming a significant component of the decision-making process.

Appendix 1 Chipper User Manual

STARKE ARVID

Chipper User's Manual



Description

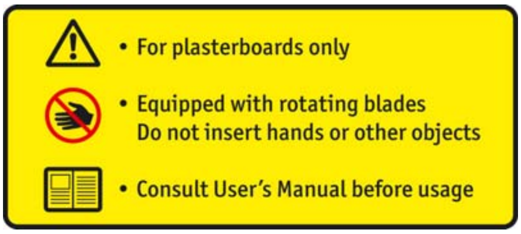
This machine is designed specifically to reduce the bulk of waste plasterboard.

It does this by reducing the waste plasterboard into manageable pieces, therefore increasing the volume that can be placed in waste containers. Two counter-rotating cylinders with blades cut the board and feed the waste pieces from the machine ready for collection.

The machine is designed to chip most types of plasterboard from 9.5 mm through to 19 mm with the exception of thermal laminates and foil-backed plasterboards.

Important!

Please read these instructions carefully to ensure the safe and effective use of this machine.



General safety rules

- For plasterboards only; other materials could damage yourself as well as the machine.
- The machine is equipped with rotating blades. Do not insert hands or other foreign objects.
- When feeding the plasterboard waste into the chipper, hold onto the back of the board until the chipper takes over the feeding. If you are feeding longer board lengths, then support the board on the back end until the machine is capable of supporting its weight. This is done to avoid the unsupported board breaking.
- Only authorised personnel should use the machine.
- To immediately stop the machine, strike the red ‘emergency stop’ button. Reset using the safe operation key.
- Keep the work area clean to avoid risks of slips, trips and falls.
- Ensure the braked wheel is engaged to prevent unnecessary movement when the machine is in operation.
- Maintain a dry and well-lit workspace area to ensure safe operation for you and other personnel.
- Never leave the machine running unattended.
- When lifting the chipper, ensure correct straps are used and are placed in the correct position. The machine should always be turned off and disconnected from the power supply before moving or lifting it.
- Metal-to-metal contact with the rotating blades could significantly reduce chipper performance as well as causing permanent damage to the chipper. Ensure no screws or foreign objects are embedded in the waste plasterboards.

Guards

- The machine is installed with an emergency stop switch that should be struck in the event of an emergency.
- The machine is equipped with a cut-out switch in the cover that will automatically stop the machine if the lid is opened during operation
- The guard for the out-feed is equipped with finger protection inside the out-feed that prevents you from touching the rotating knives.
- The in-feed has a protection that is designed to prevent operatives from placing their hands within the machine.
- The scrap outlet has a protection that is designed to prevent operatives from placing their hands within the machine.
- **Do not** attempt to modify, alter or tamper with any of the guards or electrical safety devices in any way.

Safety tests

Check safe operation of safety cut-outs daily prior to commencement of work.

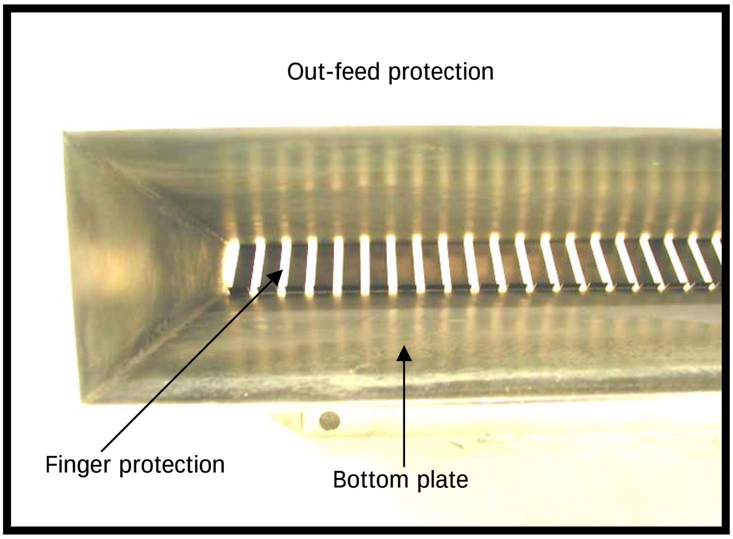
If any items below fail the safety tests, the machine must not be used!

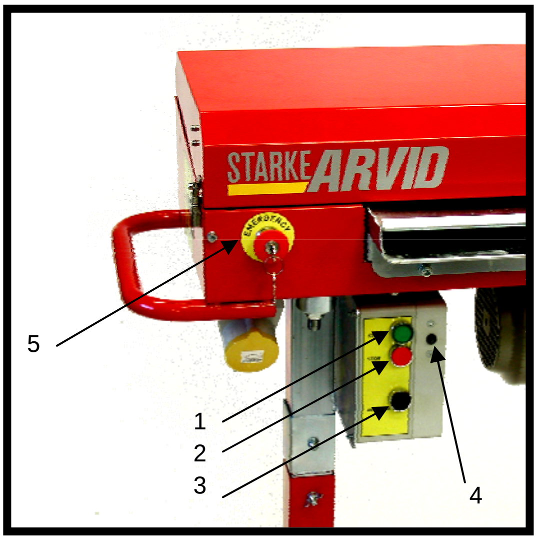
1. With the machine running, lift the cover. This will cause the machine to stop.

2. With the machine running, strike the emergency stop button. This will cause the machine to stop.

3. Remove plug to isolate the machine. Measure the gap between the finger protection and the bottom plate on the out-feed. If the gap is greater than 3 mm, replace the finger protection (see photo 1).

Photo 1





Control panel key

1 Green ‘Start’ button
2 Red ‘Stop’ button
3 Black ‘Reverse’ button
4 15 amp fuse (push button in to reset)
5 Emergency stop

Note: *If the emergency stop is activated, it requires a key to unlock it.*

Operating instructions

1. Locate the chipper on flat, even ground as near as practical to a 32-amp site transformer to reduce the length of extension cable to minimise voltage drop and gain the maximum power from the machine.
2. Choose a suitable collection method.
   i. If filling directly into large waste skips, place the chipper at the open ends of the skip.

   ii. If filling 1 tonne (dumpy type) waste sacks, support the sides of the bags with adequate framing or use recommended Starke Arvid bag supports.

   iii. When using Starke Arvid waste bins, operate the machine with the stand in the lower position. This will also improve the ergonomic operation of the machine.
3. Apply the brake on the locking wheel to prevent unnecessary movement.
4. Turn on the machine by pressing the green 'Start' button. The rotating blades start and the machine is ready to use.
5. Use only clean waste plasterboard with the machine. Avoid wet or damp boards, and ensure that they are free from screws, metal or other contaminants.
6. When feeding the plasterboard waste into the chipper, hold onto the back of the board until the chipper takes over the feeding. If you are feeding longer board lengths, support the board on the back end until the machine is capable of supporting its weight. This is done to avoid the unsupported board breaking.
7. The machine is capable of chipping most plasterboard up to a width of 700 mm and a thickness of between 9.5 and 19 mm.
8. To stop the machine, press the red 'Stop' button.
9. In the event of a **material blockage**:
   i. Press the red 'Stop' button or reset the 15-amp fuse if it has tripped.

   ii. Press the reverse switch and allow plasterboard pieces to return to the feed side of machine.

   iii. When the obstruction is clear, release the black reverse button and remove the plasterboard.

   iv. Open the lid and visually inspect the machine for loose debris within the machine. Remove the remaining material from the machine.

   Note: If this operation fails, it may be necessary to reduce the tension on the two spring adjusters by releasing the nuts. Do not remove fully. Repeat the procedure as described above. When finished, retighten the spring adjuster to the fixed original position.

Care and maintenance

The chipper is designed to be relatively maintenance free. However, regular inspection and, if necessary, replacement of worn parts will ensure the maximum performance of the machine.

Before carrying out any maintenance work on the chipper, please ensure you disconnect it from the power supply!

- Check rotating parts for evidence of damage. If necessary, contact Starke Arvid for advice/instructions about matters relating to servicing, lubrication and changing of blades (daily).
- Lightly grease the gears using lithium-based grease type KP2K-20 (monthly).
- Grease the bearings using lithium-based grease type KP2K-20 (monthly). Avoid over packing the bearings.
- The gearbox is a sealed for life unit. However, if the chipper is placed on its side, fluid may leak from the breather system. The gearbox requires Shell Tivela S320, maximum volume 0.45 litres.
- Clean the machine regularly using a soft brush or damp cloth; remove any debris from the scrap outlet (weekly).

After any maintenance procedures, it is important to carry out the 'safety test' referred to earlier in the general safety rules section.

Chipper fails to start

- Ensure all electrical cables are plugged in and the power supply is switched on.
- Release the emergency stop switch with the key.
- Ensure lid is correctly closed to disengage the safety cut-out protection.
- Check the 15 amp reset fuse.
- Check if plasterboard is jammed in the machine.
- Press the green 'Start' button.

Technical specification

Power supply:	110 volts, 50 Hz, 18.2 amp
Motor power:	1.5 kW
Geared output /final drive speed:	25 metres/minute
Maximum sound power level:	<80 dB(A)
Operating thickness:	9.5–19 mm
Operating width:	<700 mm
Weight:	145 kg
Work height:	900 or 1,110 mm
Overall size:	1,270 mm (length) × 770 mm (width) × 1,035 or 1,245 mm (height)

Notes:

STARKE ARVID

CEDOK 1.0

DECLARATION OF CONFORMITY

(Directive 98/37/EC, article 4.2 and Appendix II A)

Manufacturer (or the manufacturers representative):

Company	Alia AB
Address	Lyckåsvägen 3, 459 22 Ljungskile
Post address	Box 93, 459 22 Ljungskile

Declare under own responsibility:

Machine type:	Chipper
Drawing nr.:	37030
Machine nr.:	

to which this declaration relates is in conformity with the following directive or other documentation of regulation:

Machinery Directive 98/37/EC.
EMC-Directive 89/336/EEC also addition 92/31/EEC and 93/68/EEC.
LVD-Directiv 73/23/EEC also addition 93/68/EEC.

Is manufactured according to (or parts of) following harmonize standards:

EN 1050

Authorized person

Place/date:	Ljungskile 2006-11-07
Name:	Jan-Erik Bark
Clarification of signature:	Jan-Erik Bark
Position:	Managing director
Company:	Alia AB
Address:	Lyckåsvägen 3, 459 22 Ljungskile
Post address:	Box 93, 459 22 Ljungskile Sweden
Tel.:	+46(0)522-22 000

Machine manufactured in Sweden by:

ALIA AB +46 522-22000
Box 93
Lyckåsvägen 3
459 22 Ljungskile
Sweden

Appendix 2 Assumptions and calculations

Assumptions

Plasterboard density

Table A1 Plasterboard density*

Type	Weight per unit area (kg/m^2)	Density (kg/m^3)
12.5 mm board	8.85	708
15 mm board	10.70	712
Average		**710**

* Data from British Gypsum

Amount of waste in skip/bin

Skips were compared before and after the use of a chipper.

Two skips from the TWC Clarence dock site were used during the Milestone 6 analysis to determine the amount of waste in a skip. The worse case percentage was used in calculations.

Table A2 Amount of waste plasterboard in skip

Parameter	Value
Waste weight	7,520 kg
Waste volume (i.e. weight/density)	7,520/710 = 10.59 m^3
Volume of skip	40 cu. yd = 30.58 m^3
Percentage of waste in skip (by volume)	10.59/30.58 = 35%

Using same percentage for a bin volume of 0.66 m^3 gives volume of plasterboard in bin:

Volume of waste plasterboard in bin = 0.66 $\times$ 0.35 = 0.231 m^3

Calculations

Table A3 TWC Clarence Dock – manual system

Floor level	29-Nov-06		30-Nov-06		1-Dec-06		4-Dec-06		5-Dec-06		6-Dec-06		7-Dec-06		8-Dec-06	
	Time (mins)	No. bins	Time (mins)	No. bins	Time (mins)	No. bins	Time (mins)	No. bins	Time (mins)	No. bins	Time (mins)	No. bins	Time (mins)	No. bins	Time (mins)	No. bins
2	40	2	15	1	15	1	20	1	0	0	240	6	35	2	35	2
3	20	1	35	1	35	1	15	1	0	0	35	2	60	4	0	0
4	20	1	35	1	35	1	20	1	0	0	180	4	15	1	40	2
5	20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	20	1	0	0	25	1	0	0	0	0	0	0	0	0	0	0
7	20	1	25	1	25	1	50	3	35	2	120	4	25	1	0	0
8	0	0	0	0	0	0	0	0	0	0	15	1	30	2	40	2
Total bins		7		4		5		6		2		17		10		6
No. of labourers	1															
	2															

Combined periods			
Total time	**Total bins collected**	**Total volume (m^3)**	**Rate (minutes/m^3)**
400	15	4.048	98.81
200	10	2.681	74.60
345	11	2.965	116.36
20	1	0.231	86.58
45	2	0.462	97.40
300	13	3.533	84.91
85	5	1.420	59.86

Average time per m^3 = 88.36 minutes/m^3 = 1.47 hours/m^3

Cost = £11.96/m^3

Table A4 TWC Clarence Dock – chipper system

Date	No. of bins	Size	Volume of bin (m^3)	Volume of waste (m^3)*	Time taken	Minutes	Level	Movement time	Total time	Time / m^3
06-Feb-07	2.75	red	0.40	0.385	12m 10s	12.17	7		12.17	31.61
07-Feb-07	1	blue	0.66	0.231	10m 40s	10.67	7		10.67	46.19
	2	red	0.40	0.28	8m 50s	8.83	7		8.83	31.54
	1	blue	0.66	0.231	9m 47s	9.78	9	15	24.78	107.27
12-Feb-07	2	red	0.40	0.28	10m 14s	10.23	7		10.23	36.54
	2	red	0.40	0.28	9m 41s	9.68	7		9.68	34.57

* Calculated using the 35% plasterboard in skip from Table A2.

Total volume of waste processed = 1.687 m^3
Total time taken = 76.36 minutes
Time to process per m^3 = 0.754 hours/m^3 = 45.26 minutes/m^3
Cost per m^3 = £6.13/m^3

Table A5 Shepherd Clarence Dock Block D – manual system

Stage 1						
Floor level	**Time (minutes)**					
	04-Dec-06	**05-Dec-06**	**07-Dec-06**	**11-Dec-06**	**12-Dec-06**	**11-Jan-07**
2						
3						
4						
5						
6		15				
7	15		90			
8			34	35	55	
Total time taken = 274 minutes = 4.567 hours						

Stage 2						
Floor level	**Time (minutes)**					
	04-Dec-06	**05-Dec-06**	**07-Dec-06**	**11-Dec-06**	**12-Dec-06**	**11-Jan-07**
2						13
3						
4						
5						
6		20				
7	15		84			
8						
Total time taken = 132 minutes = 2.2 hours						

Stage 3						
Floor level	**Time (minutes)**					
	04-Dec-06	**05-Dec-06**	**07-Dec-06**	**11-Dec-06**	**12-Dec-06**	**11-Jan-07**
2						13
3						
4						
5						
6		15				
7	10		61			
8						
Total time taken = 99 minutes = 1.65 hours						

Amount of plasterboard processed	
Total number of bins	23
Volume of bin	0.66 m^3
Percentage of plasterboard in bin (from Table A2)	35%
Volume of plasterboard in bin	0.231 m^3
Total volume of plasterboard processed	5.313 m^3

	Stage		
	1	**2**	**3**
Rate (hour/m^3)	0.86	0.41	0.31
Rate (minutes/m^3)	51.57	24.84	18.63
Cost (£/m^3)	**6.98**	**3.36**	**2.52**

Table A6 Shepherd Clarence Dock Block D – chipper system

Stage 3

Date	No. of skips	Level	Size (cu. yd)	Volume of skip (m^3)	Factored volume (2/3) of skip	Volume of plasterboard in skip (m^3)*	Time taken (min)
06-Feb-07	1	11	8	6.1	4.03	2.55	51.00
07-Feb-07	1	11	8	6.1	4.03	2.55	38.13
w/c 12-Mar-07	1	13	8	6.1	4.03	2.55	100.00
	1	13	8	6.1	4.03	2.55	80.00
14-Feb-07	1	13	8	6.1	4.03	2.55	38.35

* Percentage of plasterboard in skip taken from average of all weighed skips

Total volume of plasterboard processed = 12.75 m^3
Total time taken = 307.5 minutes = 5.12 hours

Table A7 Shepherd Clarence Dock Block C2 (chipper system) – percentage of plasterboard in skip

Weight of plasterboard*	2.4 tonnes = 2,400 kg
Density of plasterboard†	710 kg/m^3
Volume of plasterboard in skip	3.380 m^3
Volume of skip	8 cu. yd = 6.116 m^3
Percentage of plasterboard in skip	55%

* Weighed by crane minus weight of skip
† Average from Table A1

Table A8 Shepherd Clarence Dock Block C2 – chipper system

Date	No. of skips	Level	Size (cu. yd)	Skip volume (m^3)	Assumed volume of plasterboard in skip (m^3)*	Factored to:	Factored volume of plasterboard in skip (m^3)	Time taken	Comments
14-Mar-07	1	7	8	6.116	3.872	1	3.87	**46**	Skip full to brim – no weight limit for Xena platform
	1	7	8	6.116	3.872	1	3.87	**42**	Full
27-Mar-07	1	7	8	6.116	3.872	1	3.87	**43**	Skip full – estimated 2.4 tonnes, crane weigh
29-Mar-07	1	7	8	6.116	3.872	2/3	2.58	**33**	Skip two-thirds full – eight bins

* Using percentage calculated from an average of all weighed skips

Total volume of waste processed = 14.199 m^3
Total time taken = 164 minutes = 2.733 hours
Time per m^3 **=** 0.193 hours/m^3 = 11.55 minutes/m^3
Cost (£/m^3) = 1.57

Table A9 St James, Cheltenham – chipper system

Skip volume = 6 cu. yd = 4.56 m^3

Plasterboard density = 710 kg/m^3 (average from Table A1)

Waste Transfer Note Reference	Date	Material	Net weight of plasterboard (tonnes)*
62311	25-Aug-06	Plasterboard un-chipped	2.34
62420	29-Aug-06	plasterboard un-chipped	2.30
62406	29-Aug-06	Plasterboard un-chipped	2.28
62559	30-Aug-06	Plasterboard chipped	2.72

* From weighbridge tickets (only what was in the skip)

Weight of plasterboard (chipped) = 2.72 tonnes

Volume of waste in skip = 3.83 m^3

Percentage of plasterboard in full skip = 84.01%

Time taken to process skip = 1.66 hours

Time taken to process 1 m^3 plasterboard = 0.43 hours/m^3 = 26.00 minutes/m^3

Labour cost per m^3 = £3.52

Table A10 The Square at Grant Central, Aylesbury – manual system

Stage 2 and 3 combined	
Plasterboard density*	710 kg/m^3
Weight processed†	198 kg
Volume of plasterboard processed	0.28 m^3
Time taken	50.29 minutes = 0.838 hours
Time taken to process per m^3 plasterboard	3.01 hrs/m^3 = 180.33 minutes/m^3
Cost per m^3 of waste processed	**£24.41**

* Average from Table A1
† Weighed on site by crane scale

Table A11 The Square at Grand Central, Aylesbury – chipper system

Stage 2 and 3 combined	
Plasterboard density*	710 kg/m^3
Weight processed†	226 kg
Volume of plasterboard processed	0.32 m^3
Time taken	28 minutes = 0.467 hours
Time taken to process per m^3 plasterboard	1.47 hours/m^3 = 87.96 minutes/m^3
Cost per m^3 of waste processed	**£11.90**

* Average from Table A1
† Weighed on site by crane scale

Table A12 Manual system – bags

Time	13 minutes
Time multiplied by four for laboratories	52 minutes
Labour (no. of people)	4
Volume of British Gypsum bag	1 m^3
Weight*	248 kg
Volume of plasterboard	0.349 m^3
Percentage plasterboard	35%
Time taken	0.867 hours
Time taken per m^3	2.48 hours
Cost per m^3	**£20.15**

* Measured by weighbridge

Table A13 Chipper system – bags

Time	23 minutes
Labour (no. of people)	1
Volume of British Gypsum bag	1 m^3
Weight*	342 kg
Volume of plasterboard	0.482 m^3
Percentage plasterboard	48.2%
Time taken	0.383 hours
Time taken per m^3	0.80 hours
Cost per m^3	**£6.462**

* NB Not wet

Table A14 Chipper system – skip

Time	71 minutes
Time multiplied by two for laboratories	142 minutes
Labour	2
Size of skip	8 cu. yd = 6.116 m^3
Weight*	2,200 kg
Volume of plasterboard in skip	3.099 m^3
Percentage of plasterboard in skip	50.664%
Time taken	2.367 hours
Time taken per m^3	0.764 hours
Cost per m^3	**£6.20**

* NB Not wet

Table A15 Kings Place, Kings Cross – chipper system

Date	Stage	Quantity (m^3)	Time (minutes)	Floor
25 April 2007	1	0.14	4	2
	2		5	
	3	n/a		
3 May 2007	1	0.28	4	0
	2		12	
9 May 2007	1	0.28	6	0
	2		12	
10 May 2007	1	0.98	24	0
	2		36	
15 May 2007	1	1.26	34	2
	2		47	
18 May 2007	1	1.12	32	2
	2		48	

Stage	Total time		Rate (hours/m^3)	Cost (£/m^3)
	Minutes	Hours		
1	104	1.73	0.43	3.47
2	160	2.67	0.66	5.33
3	0	0.00	0.00	0.00
Total	**264**	**4.40**		**8.80**

Total quantity of material = 4.06 tonnes

Appendix 3 Environmental analysis: assumptions and constraints

A number of constraints made it necessary to make certain assumptions in order to facilitate an effective estimation of the carbon savings achievable.

An absence of data on chipped skips across projects

The project team felt that it was important that the environmental analysis should allow for some comparison in emission savings between different types of project. In order to do this it was necessary to use historical data from Taylor Woodrow projects. Since these projects had not (apart from Clarence Dock) had a chipper on site, the project team instead decided to undertake controls to assess the weight of plasterboard that different waste receptacles can hold with and without the use of a chipper.

As such, and although the historic data contain information on the number and weight of skips leaving sites, only the total weight of plasterboard waste generated on each project has been used. In each case, the total weight was divided by the respective control weights for chipped and un-chipped skips/bags to give an estimate of the 'best case' number of skips filled during the project for under both scenarios.

Clearly there will be a difference between the number of control un-chipped skips estimated using the total waste weight – which would represent a scenario where all skips are filled to capacity – and the number of un-chipped skips actually used on the projects. But for comparison with the chipped skips (for which there are no data), it is more pertinent to use the control un-chipped skip weight as the unit weight. The outputs of the analysis are thus very much 'best case' scenarios. In reality, a number of other factors may mean that un-chipped or chipped skips/bags will leave site without being full.

Since it is anticipated that larger skips will also further reduce the total distance travelled during each project (and therefore carbon emissions), the project team scaled up unit weights from the control 8 cu. yd skips to represent 16 and 40 cu. yd skip sizes. From this, it was possible to derive total projected carbon emissions for chipped and un-chipped plasterboard for each skip size and on each project. This approach was not applicable for projects that used British Gypsum bags (only one size exists).

Available emissions data

Emissions data (gCO_2/km) for both rigid and articulated HGVs are available from the National Environmental Technology Centre (NETCEN)[9] Vehicle Emission Factor Database. These data have been used to derive an estimate of the total emissions per project for un-chipped and chipped plasterboard collection based on the total distances travelled.

The data were taken from the Vehicle Emission factor Database v02.8.xls issued in January 2003. This database was produced by NETCEN as part of the National Atmospheric Emissions Inventory (NAEI) Programme in consultation with the Transport Research Laboratory (TRL). This includes adoption of the new TRL factors for Euro I and II vehicles and takes into account the reduction in emissions anticipated for Euro III and IV vehicles.

A lack of vehicle-specific data

Contact was initially made with Wastecycle (the contractor responsible for transporting skipped waste to British Gypsum facilities) to request makes and models of their lorries used for 8, 16 and 40 cu. yd skip removal. The various manufacturers of these vehicles were then consulted to obtain specific emissions data for each lorry type. However, manufacturers only provided information on which Euro standard each vehicle meets.

Therefore, there was no way of distinguishing between the emission levels of rigid lorries removing the three different sizes of skips from sites. The emissions per mile value provided by NETCEN for rigid HGVs were used instead. However, this did not distinguish between rigid HGV types and thus it was assumed that emissions were the same regardless of what size of skip was being removed. Similarly, no means was found by which to calculate

[9] *Now part of AEA Energy & Environment (from the AEA Group)*

differences in emissions due to increased load on a lorry. It was also necessary to assume that emissions were the same regardless of the weight of the skip or bag on the lorry.

Euro standards

The NETCEN data are differentiated on the basis on Euro standards. It was assumed that the vehicles in use would certainly not all be Euro IV standard (2005-2008) and the Euro II standard (1995-1999) was selected instead as many HGVs probably fall within this age category. It should be noted that this was the most recent data available from NETCEN.

For British Gypsum bags, the emissions per mile of a Euro II articulated lorry were used. British Gypsum uses articulated vehicles and rigid vehicles, but it was felt that it would benefit the analysis to assume articulated lorries were used in each case. An articulated lorry of this type can hold 25 bags and a total weight of 25 tonnes.

HGV average speeds

The NETCEN database allows for the selection of different average speeds to be defined since this has a significant impact on the emissions per mile. An average speed of 40 miles/hour (64 km/hour) was assumed for this study. This is based on the fact that the lorries will be travelling in many cases on city roads, trunk roads and motorways.

Variation in emissions with different loads

It was not possible to access data that compare emissions from different Euro II class HGVs under different load profiles. While emissions per mile increase with a greater load, it is anticipated that the reduced total number of journeys required throughout a project would easily offset this small increase in emissions per journey. As such, it was necessary to assume that emissions would be the same despite differences in the weight of loads of chipped versus un-chipped skips and bag collections.

Transport distances

Two British Gypsum recycling centres serve all UK sites. Sites within London and the south east are served by the centre at Robertsbridge, East Sussex, and those elsewhere in the UK by the centre at East Leake in Leicestershire. Distances have been calculated accordingly depending on the location of each project site.

For each skip movement, an outward and return journey from the relevant recycling centre was included. For British Gypsum bag collection, however, each lorry usually visits a number of sites on each journey. It was not possible to factor this in and therefore it was decided to include only the return leg of the journey for British Gypsum bag sites.

The methodology presented above was expected to be the most effective method with which to derive the potential projected carbon savings achievable on a range of project types through use of the chipping machine, and as such get the most out of available data. The volume of historic data available on un-chipped conventional plasterboard disposal is a useful resource and was seen as adding value to the project. Through use of unit data derived through controlled filling of 8 cu. yd skips (and scaling this information up to 16 and 40 cu. yd skips), it was possible to use these existing data.

Appendix 4 Examples of CO_2 emission calculations

Summary sheet

Bags	Total waste (tonnes)	Unit distance (miles)	Total tCO_2 un-chipped	Total tCO_2 chipped	Total savings (tCO_2)		
Orsett Village	2,019	54	44.61	32.15	12.47		
GUV	383	85	13.27	9.56	3.71		
Western Harbour	171	297	20.81	15.00	5.82		
Skips	**Total waste (tonnes)**	**Unit distance (miles)**	**Total tCO_2 un-chipped**	**Total tCO_2 chipped 8 cu. yd**	**Total savings 8 cu. yd (tCO_2)**	**Total savings 16 cu. yd (tCO_2)**	**Total savings 40 cu. yd (tCO_2)**
Higher Broughton	189	209	13.78	11.72	2.05	1.03	0.41
Victoria Wharf (phases 2 & 3)	217	336	25.49	21.69	3.80	1.90	0.76
Clarence Dock	58	161	3.27	2.78	0.49	0.24	0.10
St Crispins	34	108	1.28	1.09	0.19	0.10	0.04
Lancaster Road	22	308	2.37	2.02	0.35	0.18	0.07

Analysis

Table C1 Comparison of bags to skips – emissions/savings

	Orsett Village	Lancaster Road
Total waste (tonnes)	2,109	22
Unit distance (miles)	54	308
Bags		
No. of journeys	238	3
Total emissions chipped (tCO_2)	32.15	2.00
tCO_2/tonne of waste	0.0159	0.091
Vehicle tCO_2/mile	2,511	17,767
8 cu. yd skips		
No. of journeys	558	6
Total emissions chipped (tCO_2)	32.35	2.02
tCO_2/tonne of waste	0.0160	0.092
Vehicle tCO_2/mile	1,076	17,666
16 cu. yd skips		
No. of journeys	279	3
Total emissions chipped (tCO_2)	16.18	1.01
tCO_2/tonne of waste	0.0008	0.046
Vehicle tCO_2/mile	1,076	17,666

Table C2 Comparison of different skips – emissions/savings

	tCO_2
Orsett Village	
Total 8 cu. yd chipped	32.35
Total 16 cu. yd chipped	16.18
Total 40 cu. yd chipped	6.47
Total 8 cu. yd un-chipped	38.02
Total 16 cu. yd un-chipped	19.01
Total 40 cu. yd un-chipped	7.60
Total 8 cu. yd un-chipped	38.02
Total 40 cu. yd chipped	6.47
Saving	**31.55**
Total 8 cu. yd chipped	32.35
Total 40 cu. yd chipped	6.47
Saving	**25.88**
Lancaster Road	
Total 8 cu. yd chipped	2.02
Total 16 cu. yd chipped	1.01
Total 40 cu. yd chipped	0.40
Total 8 cu. yd un-chipped	2.37
Total 16 cu. yd un-chipped	1.18
Total 40 cu. yd un-chipped	0.47
Total 8 cu. yd un-chipped	2.37
Total 40 cu. yd chipped	0.40
Saving	**1.97**
Total 8 cu. yd chipped	2.02
Total 40 cu. yd chipped	0.40
Saving	**1.61**

Table C3 Comparison of barge and road

Kings Cross	tCO_2
Average total emissions on job chipped*	0.07
Barge emissions on job	0.01

* Average of bags, 8, 16 and 40 cu. yd skips

Table C4 Comparison of different recycling centre locations

Clarence Dock	tCO_2 **(based on 8 cu. yd skip)**
Total emissions on job chipped	0.07
As skips	
Total emissions on job chipped	2.78
Savings from having close recycling centre	**2.71**

In Tables C5 to C10, yellow cells contain data that are either generated by the spreadsheet or are a consistent set of values. Green cells show calculated emissions.

Table C5 Orsett village – bag

WASTE	
Weight of chipped bag	0.34
Weight of un-chipped bag	0.245
Total weight of waste on project (tonnes)	2,019
Estimated number of chipped bags on project	5,938
Estimated number of un-chipped bags on project	8,241
TRANSPORT	
Number of bags per lorry (articulated)	25
Max weight (tonnes) capacity of lorry (articulated)	25
Number of journeys per project (chipped)	238
Number of journeys per project (un-chipped)	330
EMISSIONS	
Emissions per mile (gCO2/mile)	2511.03
Length of journey (miles)	53.90
Emissions per journey (gCO2)	135,344.52
Total miles travelled on job chipped	12,802.84
Total miles travelled on job unchipped	17,767.20
Total emissions on job chipped (gCO2)	32,148,303.51
Total emissions on job un-chipped (gCO2)	44,613,972.22
TOTAL EMISSIONS SAVING gC02	12,465,668.71
TOTAL EMISSIONS SAVING kgC02	12,465.67
TOTAL EMISSIONS SAVING tC02	12.47
TOTAL EMISSIONS CHIPPED (tCO2)	32.15
Percentage Saving	27.94
tCO2 per tonne (bags)	0.016

Table C6 GUV – bag

WASTE	
Weight of chipped bag	0.34
Weight of un-chipped bag	0.25
Total weight of waste on project (tonnes)	383
Estimated number of chipped bags on project	1,126
Estimated number of un-chipped bags on project	1,563
TRANSPORT	
Number of bags per lorry (articulated)	25
Max weight (tonnes) capacity of lorry (articulated)	25
Number of journeys per project (chipped)	45
Number of journeys per project (un-chipped)	63
EMISSIONS	
Emissions per mile (gCO2/mile)	2,511.03
Length of journey (miles)	84.50
Emissions per journey (gCO2)	212,182.04
Total miles travelled on job chipped	3,807.47
Total miles travelled on job unchipped	5,283.84
Total emissions on job chipped	9,560,672.87
Total emissions on job un-chipped	13,267,872.56
TOTAL EMISSIONS SAVING gC02	3,707,199.68
TOTAL EMISSIONS SAVING kgC02	3,707.20
TOTAL EMISSIONS SAVING tC02	3.71
TOTAL EMISSIONS CHIPPED (tCO2)	9.56
Percentage Saving	27.94
tCO2 per tonne (bags)	0.02

Table C7 Western harbour – bag

WASTE	
Weight of chipped bag	0.34
Weight of un-chipped bag	0.245
Total weight of waste on project (tonnes)	171
Estimated number of chipped bags on project	503
Estimated number of un-chipped bags on project	698
TRANSPORT	
Number of bags per lorry (articulated)	25
Max weight (tonnes) capacity of lorry (articulated)	25
Number of journeys per project (chipped)	20
Number of journeys per project (un-chipped)	28
EMISSIONS	
Emissions per mile (gCO2/mile)	2,511.03
Length of journey (miles)	296.90
Emissions per journey (gCO2)	745,524.81
Total miles travelled on job chipped	5,972.93
Total miles travelled on job unchipped	8,288.96
Total emissions on job chipped	14,998,204.94
Total emissions on job un-chipped	20,813,835.43
TOTAL EMISSIONS SAVING gC02	5,815,630.49
TOTAL EMISSIONS SAVING kgC02	5,815.63
TOTAL EMISSIONS SAVING tC02	5.82
TOTAL EMISSIONS CHIPPED (tCO2)	15.00
Percentage Saving	27.94
tCO2 per tonne (bags)	0.09

Table C8 Higher Broughton – skip

WASTE		**WASTE**		**WASTE**	
Weight of control 8 yard chipped skip (tonnes)	3.62	Weight of control 16 yard chipped skip (tonnes)	7.24	Weight of control 40 yard chipped skip (tonnes)	18.10
Weight of control 8 yard un-chipped skip (tonnes)	3.08	Weight of control 16 yard un-chipped skip (tonnes)	6.16	Weight of control 40 yard un-chipped skip (tonnes)	15.40
Total weight of waste on project (tonnes)	189.00	Total weight of waste on project (tonnes)	189.00	Total weight of waste on project (tonnes)	189.00
Estimated number of chipped skips on job	52.21	Estimated number of chipped skips on job	26.10	Estimated number of chipped skips on job	10.44
Estimated number of un-chipped skips	61.36	Estimated number of un-chipped skips	30.68	Estimated number of un-chipped skips	12.27
TRANSPORT		**TRANSPORT**		**TRANSPORT**	
Max Weight of Skip on Lorry (must be > than B3)		Max Weight of Skip on Lorry (must be > than B3)		Max Weight of Skip on Lorry (must be > than B3)	
Number of journeys per project (chipped)	52.21	Number of journeys per project (chipped)	26.10	Number of journeys per project (chipped)	10.44
Number of journeys per project (un-chipped)	61.36	Number of journeys per project (un-chipped)	30.68	Number of journeys per project (un-chipped)	12.27
EMISSIONS		**EMISSIONS**		**EMISSIONS**	
Emissions per mile (gCo2/mile)	1076.14	Emissions per mile (gCo2/mile)	1076.14	Emissions per mile (gCo2/mile)	1076.14
Length of journey (mile)	208.60	Length of journey (mile)	208.60	Length of journey (mile)	208.60
Emissions per journey (gCO2)	224482.80	Emissions per journey (gCO2)	224482.80	Emissions per journey (gCO2)	224482.80
Total miles travelled on job chipped	10890.99	Total miles travelled on job chipped	5445.50	Total miles travelled on job chipped	2178.20
Total miles travelled on job unchipped	12800.45	Total miles travelled on job unchipped	6400.23	Total miles travelled on job unchipped	2560.09
Total emissions on job chipped	11720234.79	Total emissions on job chipped	5860117.40	Total emissions on job chipped	2344046.96
Total emissions on job un-chipped	13775081.15	Total emissions on job un-chipped	6887540.58	Total emissions on job un-chipped	2755016.23
TOTAL EMISSIONS SAVING gC02	2054846.36	TOTAL EMISSIONS SAVING gC02	1027423.18	TOTAL EMISSIONS SAVING gC02	410969.27
TOTAL EMISSIONS SAVING kgC02	2054.85	TOTAL EMISSIONS SAVING kgC02	1027.42	TOTAL EMISSIONS SAVING kgC02	410.97
TOTAL EMISSIONS SAVING tC02	2.05	TOTAL EMISSIONS SAVING tC02	1.03	TOTAL EMISSIONS SAVING tC02	0.41
TOTAL EMISSIONS ON JOB CHIPPED (tCO2)	11.72		5.86		2.34

Table C9 Victoria Wharf – skip

	8 yard	16 yard	40 yard
WASTE			
Weight of control chipped skip (tonnes)	3.62	7.24	18.10
Weight of control un-chipped skip (tonnes)	3.08	6.16	15.40
Total weight of waste on project (tonnes)	217.00	217.00	217.00
Estimated number of chipped skips on job	59.94	29.97	11.99
Estimated number of un-chipped skips	70.45	35.23	14.09
TRANSPORT			
Max Weight of Skip on Lorry (must be > than B3)			
Number of journeys per project (chipped)	59.94	29.97	11.99
Number of journeys per project (un-chipped)	70.45	35.23	14.09
EMISSIONS			
Emissions per mile (gCo2/mile)	1076.14	1076.14	1076.14
Length of journey (mile)	336.2	336.2	336.2
Emissions per journey (gCO2)	361798.27	361798.27	361798.27
Total miles travelled on job chipped	20153.43	10076.71	4030.69
Total miles travelled on job unchipped	23686.82	11843.41	4737.36
Total emissions on job chipped	21687907.23	10843953.61	4337581.45
Total emissions on job un-chipped	25490332.52	12745166.26	5098066.50
TOTAL EMISSIONS SAVING gC02	3802425.29	1901212.65	760485.06
TOTAL EMISSIONS SAVING kgC02	3802.43	1901.21	760.49
TOTAL EMISSIONS SAVING tC02	3.80	1.90	0.76
TOTAL EMISSIONS ON JOB CHIPPED (tCO2)	21.69	10.84	4.34

Table C10 Clarence Dock – skip

WASTE		WASTE		WASTE	
Weight of control 8 yard chipped skip (tonnes)	3.62	Weight of control 16 yard chipped skip (tonnes)	7.24	Weight of control 40 yard chipped skip (tonnes)	18.10
Weight of control 8 yard un-chipped skip (tonnes)	3.08	Weight of control 16 yard un-chipped skip (tonnes)	6.16	Weight of control 40 yard un-chipped skip (tonnes)	15.40
Total weight of waste on project (tonnes)	58.25	Total weight of waste on project (tonnes)	58.25	Total weight of waste on project (tonnes)	58.25
Estimated number of chipped skips on job	16.09	Estimated number of chipped skips on job	8.05	Estimated number of chipped skips on job	3.22
Estimated number of un-chipped skips	18.91	Estimated number of un-chipped skips	9.46	Estimated number of un-chipped skips	3.78
TRANSPORT		**TRANSPORT**		**TRANSPORT**	
Max Weight of Skip on Lorry (must be > than B3)		Max Weight of Skip on Lorry (must be > than B3)		Max Weight of Skip on Lorry (must be > than B3)	
Number of journeys per project (chipped)	16.09	Number of journeys per project (chipped)	8.05	Number of journeys per project (chipped)	3.22
Number of journeys per project (un-chipped)	18.91	Number of journeys per project (un-chipped)	9.46	Number of journeys per project (un-chipped)	3.78
EMISSIONS		**EMISSIONS**		**EMISSIONS**	
Emissions per mile (gCo2/mile)	1076.14	Emissions per mile (gCo2/mile)	1076.14	Emissions per mile (gCo2/mile)	1076.14
Length of journey (mile)	160.8	Length of journey (mile)	160.8	Length of journey (mile)	160.8
Emissions per journey (gCO2)	173043.31	Emissions per journey (gCO2)	173043.31	Emissions per journey (gCO2)	173043.31
Total miles travelled on job chipped	2587.46	Total miles travelled on job chipped	1293.73	Total miles travelled on job chipped	517.49
Total miles travelled on job unchipped	3041.10	Total miles travelled on job unchipped	1520.55	Total miles travelled on job unchipped	608.22
Total emissions on job chipped	2784467.66	Total emissions on job chipped	1392233.83	Total emissions on job chipped	556893.53
Total emissions on job un-chipped	3272653.55	Total emissions on job un-chipped	1636326.77	Total emissions on job un-chipped	654530.71
TOTAL EMISSIONS SAVING gC02	488185.89	TOTAL EMISSIONS SAVING gC02	244092.94	TOTAL EMISSIONS SAVING gC02	97637.18
TOTAL EMISSIONS SAVING kgC02	488.19	TOTAL EMISSIONS SAVING kgC02	244.09	TOTAL EMISSIONS SAVING kgC02	97.64
TOTAL EMISSIONS SAVING tC02	0.49	TOTAL EMISSIONS SAVING tC02	0.24	TOTAL EMISSIONS SAVING tC02	0.10
TOTAL EMISSIONS ON JOB CHIPPED (tCO2)	2.78		1.39		0.56

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